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NARRATIVE REVIEW

The role of maltodextrin in iron nanoparticle formulations for food fortification and pharmaceutical applications : A scoping review

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Abstract

Background: Iron nanoparticle formulation is an innovative approach to enhance the stability and bioavailability of iron, which is crucial in addressing global iron deficiency. However, conventional iron supplementation strategies, like oral ferrous sulfate, face limitations in absorption and bioavailability. Specifically, dietary inhibitors and gastrointestinal conditions can impede iron uptake. Moreover, oral iron supplements often cause side effects such as nausea, constipation, and abdominal discomfort, affecting patient compliance. These challenges highlight the need for innovative approaches to enhance iron delivery. In this context, nanotechnology offers a promising solution to conventional iron supplementation limitations. Iron nanoparticles provide improved solubility, targeted delivery, and controlled release, thereby enhancing therapeutic effectiveness. Both in vitro and in vivo bioavailability studies have demonstrated that nanoparticle-based formulations improve iron absorption and reduce side effects. By improving iron absorption and reducing side effects, nanoparticle-based formulations represent a significant advancement in IDA management. Maltodextrin, a water-soluble and neutral starch-derived polysaccharide, serves as an effective encapsulating agent in nanoparticle formulation, enhancing stability, solubility, and controlled release, thereby overcoming limitations of traditional iron supplementation. Both in vitro and in vivo studies have demonstrated the potential of maltodextrin-based iron nanoparticles to improve bioavailability and therapeutic outcomes.

Objective: This scoping review aims to explore the role of maltodextrin in iron nanoparticle formulations based on the latest scientific evidence.

Methods : A systematic literature search was conducted across four databases: PubMed, ScienceDirect, Scopus, and SpringerLink, using structured keywords. Inclusion criteria consisted of original English language articles published between 2019 and 2024 that discussed the use of maltodextrin in iron nanoparticle systems. Exclusion criteria The selection and data synthesis process followed PRISMA-ScR guidelines.

Results : Out of 8620 articles identified, three met the inclusion criteria: Arazo-Rusindo et al. (2023), Kumari et al. (2023), and Baldelli et al. (2023). These studies demonstrated that maltodextrin acts as a carrier, stabilizer, and bioavailability enhancer, while also improving encapsulation efficiency and nanoparticle stability.

Conclusions : These findings highlight the potential of maltodextrin in developing functional food products and pharmaceutical formulations based on iron nanoparticles; however, further research is needed to optimize formulations and evaluate long-term safety.

Keywords: bioavailability, encapsulation, iron, maltodextrin, nanoparticles

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Introduction

One of the main nutritional problems commonly found among adolescent girls is anemia. According to the World Health Organization (WHO), the global prevalence of anemia among adolescents ranges from 40% to 88%. In developing countries, adolescent girls account for up to 53.7% of the total population affected by anemia.[1] This condition arises primarily from insufficient iron availability, leading to diminished hemoglobin synthesis and compromised oxygen transport.[2,3] The health ramifications of IDA (iron deficiency anemia) are profound, encompassing impaired cognitive and motor development in children, increased susceptibility to infections, and elevated risks of maternal and neonatal complications, including preterm birth and low birth weight.[4,5] Despite concerted public health efforts, IDA continues to impose significant morbidity and mortality burdens, particularly in low and middle income countries.[6]

Conventional iron supplementation strategies, such as oral ferrous sulfate administration, often encounter limitations related to suboptimal absorption and bioavailability.[7,8] Factors such as dietary inhibitors (e.g., phytates, polyphenols) and gastrointestinal conditions can impede iron uptake.[2] Moreover, oral iron supplements are frequently associated with gastrointestinal side effects, including nausea, constipation, and abdominal discomfort, which can adversely affect patient compliance.[9] These challenges underscore the necessity for innovative approaches to enhance iron delivery and efficacy.[10]

Nanotechnology has emerged as a promising avenue to address the shortcomings of traditional iron supplementation.[11,12] Iron nanoparticles offer several advantages, including improved solubility, targeted delivery, and controlled release profiles, which collectively enhance therapeutic effectiveness.[12] Both in vitro and in vivo studies have provided evidence supporting the enhanced bioavailability and reduced side effects of nanoparticle-based iron formulations.[13] By facilitating more efficient iron absorption and reducing systemic side effects, nanoparticle-based formulations represent a significant advancement in the management of IDA.[14,15]

Within the realm of nanoparticle engineering, excipients play a crucial role in determining the stability, bioavailability, and overall performance of the formulation.[16,17] Maltodextrin, a polysaccharide derived from starch, has garnered attention for its functional properties in nanoparticle systems.[18] Its inclusion can enhance the stability of iron nanoparticles, improve encapsulation efficiency, and facilitate sustained release, thereby potentially augmenting iron bioavailability.[12] Despite these promising attributes, the specific role and efficacy of maltodextrin in iron nanoparticle formulations remain underexplored in the current literature.[19] Given the existing knowledge gaps, a comprehensive scoping review is warranted to systematically examine the role of maltodextrin in iron nanoparticle formulations. This review aims to collate and analyze peer-reviewed studies published between 2019 and 2024, focusing on the impact of maltodextrin on iron bioavailability, nanoparticle stability and encapsulation efficiency in the pharmaceuticals product. Both in vitro and in vivo evidence will be considered to inform future research directions and contribute to the development of more effective iron supplementation strategies.

Maltodextrin nanoparticles serve as effective carriers with considerable encapsulation efficiency, especially when combined with lipids to improve bioactive loading and stability. Encapsulation efficiency in such systems is a product of optimal formulation

strategies that leverage maltodextrin's biocompatible and biodegradable properties enhanced by synergistic components, positioning maltodextrin as a promising matrix for nanoparticle-mediated delivery applications.[20] Encapsulation techniques enhance bioavailability by protecting iron nanoparticles from degradation in the gastrointestinal tract and enabling controlled release, thereby improving absorption and therapeutic efficacy.[21] By elucidating these aspects, the review seeks to inform future research directions and contribute to the development of more effective iron supplementation strategies.

Methods

Scoping Review Framework

This scoping review was conducted following the methodological framework established by Arksey and O'Malley, which provides a systematic approach for mapping key concepts and identifying gaps within existing literature. To enhance methodological rigor, we incorporated refinements suggested by Levac, including the clarification of research questions, application of an iterative team-based approach, and integration of stakeholder consultation throughout the review process. The reporting of this study adheres to the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) guidelines, ensuring transparency and completeness in the description of methods and presentation of findings.[22]

Research Questions

The review was guided by three central research questions designed to comprehensively explore the role of maltodextrin in iron nanoparticle formulations. The first question was to investigates the functional role of maltodextrin within these formulations. The second was to examines how nanoparticles formulated with maltodextrin are characterized in terms of their physicochemical properties. The third was to addresses the formulation methods employed and the excipient combinations used alongside maltodextrin in developing iron nanoparticles.

PCC Eligibility Framework

Inclusion criteria were developed based on the Population-Concept-Context (PCC) framework, which is widely recommended for scoping reviews.[23] The population of interest includes studies focusing on iron nanoparticle formulations. The concept involves the use of maltodextrin in these formulations. The context encompasses experimental or formulation-based studies investigating nano iron systems. This framework allowed for targeted yet comprehensive inclusion of relevant studies that provide insight into the application of maltodextrin in iron nanoparticle research.

Eligibility Criteria

Studies were included if they met specific criteria: articles published between 2019 and 2024; peer-reviewed and written in English; explicitly using maltodextrin in iron nanoparticle formulations; experimental in nature, including in vitro, in vivo, stability, or

characterization studies; full-text available; and reporting at least one formulation characteristic such as particle size or encapsulation efficiency. Studies were excluded if they were review articles, systematic reviews, or meta-analyses; did not explicitly use maltodextrin; focused on nanoparticles other than iron; were published in languages other than English or lacked full-text availability; or were published prior to 2019. These criteria ensured the inclusion of relevant, high-quality empirical studies.

Literature Search Strategy

A comprehensive literature search was conducted across four major electronic databases: PubMed, Scopus, ScienceDirect, and SpringerLink. The search strategy combined specific keywords with Boolean operators to identify relevant studies. For example, the PubMed search string used was: ("maltodextrin") AND ("iron nanoparticles" OR "nano iron" OR "iron nanoformulation" OR "iron encapsulation"). Search terms and strategies were adapted appropriately for each database to accommodate differences in indexing and search functionalities, thereby maximizing the retrieval of pertinent literature.

Study Selection Process

All identified articles were imported into Mendeley for systematic screening, and duplicate records were removed prior to the selection process. The screening was conducted in two stages: first, titles and abstracts were reviewed to exclude articles that clearly did not meet the predefined inclusion criteria; second, the full texts of the remaining articles were assessed for eligibility. Both stages of screening were conducted independently by two reviewers to ensure objectivity and reduce the risk of individual bias. Any discrepancies or disagreements between reviewers were resolved through discussion, and when consensus could not be reached, a third reviewer was consulted for arbitration. To minimize the risk of selection bias and enhance screening consistency, all reviewers received prior training and calibration using a small sample of studies to harmonize their understanding of the eligibility criteria. A standardized screening form was employed to guide decision making and to systematically document inclusion or exclusion reasons. The use of Mendeley facilitated accurate organization, reference management, and removal of duplicates, while thorough documentation of reviewer decisions ensured transparency, reproducibility, and auditability throughout the review process.

Data Extraction

Data from eligible studies were charted using a structured extraction form capturing key information including article title, authorship and year of publication, country of origin, research objectives, nanoparticle type, the role of maltodextrin, formulation methods applied (e.g., spray drying, freeze drying), characterization data such as particle size, encapsulation efficiency, and stability, as well as main findings. This systematic approach facilitated a comprehensive mapping of existing research on maltodextrin's application in iron nanoparticle formulations.

Data Analysis

Extracted data were analyzed through descriptive narrative synthesis [24]. Findings were organized in tables and figures that highlighted key aspects such as the functional roles of maltodextrin (e.g., stabilizer, cryoprotectant, carrier), types of formulation methods employed, and co-formulants used alongside maltodextrin. This analytical strategy enabled the identification of trends, patterns, and research gaps, providing an integrative overview of the current landscape in iron nanoparticle formulation involving maltodextrin. The synthesis also allowed for the evaluation of how maltodextrin contributes to formulation efficiency, stability, and bioavailability outcomes, thereby offering valuable insights for future research directions and potential improvements in nanoparticle-based iron delivery systems.

Data Mapping

Data mapping was systematically carried out to synthesize and report the characteristics and findings of the eligible studies based on the predefined inclusion criteria. The extracted data were organized and presented in Table 1, which includes detailed information on the article title, authors (year), country of origin, research objective, formulation method, the specific function of maltodextrin within the nanoparticle system, nanoparticle characterization, and the key findings of each study. This structured summary aims to provide a comprehensive overview of the current evidence regarding the role of maltodextrin in iron nanoparticle formulation.

Results

Article Characteristics

Figure 1 presents the systematic selection process of studies included in this scoping review. An initial total of 8,260 records were retrieved from four electronic databases: ScienceDirect (n = 84), Scopus (n = 1), PubMed (n = 8,153), and SpringerLink (n = 22). Following the removal of seven duplicate entries, 8,253 records were subjected to title and abstract screening. During this phase, 8,241 records were excluded for not meeting the predefined inclusion criteria. Specifically, 4,433 articles were published outside the designated timeframe of 2019–2024, 2,330 articles lacked accessible full-text, and 1,478 employed study designs that did not align with the eligibility criteria for experimental research. Subsequently, 12 full-text articles were assessed for eligibility. Of these, nine articles were excluded due to the absence of maltodextrin in the nanoparticle formulation or a focus on non-iron nanoparticles. Ultimately, three studies met all inclusion criteria and were included in the final synthesis.

Study Characteristics and Objectives

Table 1 summarizes the key characteristics of the three studies included in this scoping review, all of which were published in 2023 by Arazo-Rusindo et al.[25], Kumari et al.[26], and Baldelli et al.[27]. These studies reflect a growing global interest in the application of maltodextrin in iron nanoparticle formulations. The studies employed diverse methodologies, ranging from in vitro models, combined in vitro/in vivo approaches, to formulation and characterization studies. Their shared objective was to improve the bioavailability, stability, and functional properties of iron in food or pharmaceutical

products, with each study focusing respectively on legume soup reformulation, millet-based pasta enrichment, and anemia recovery in animal models. The legume soup reformulation targets older adults by enhancing micronutrient bioaccessibility, particularly iron, through stable iron nanoparticles. The millet-based pasta enrichment focuses on incorporating encapsulated ferrous gluconate to improve solubility and stability, producing a nutrient-fortified functional food. Both demonstrate the use of maltodextrin as an effective encapsulating agent to improve iron delivery and nutritional value.[25,28]

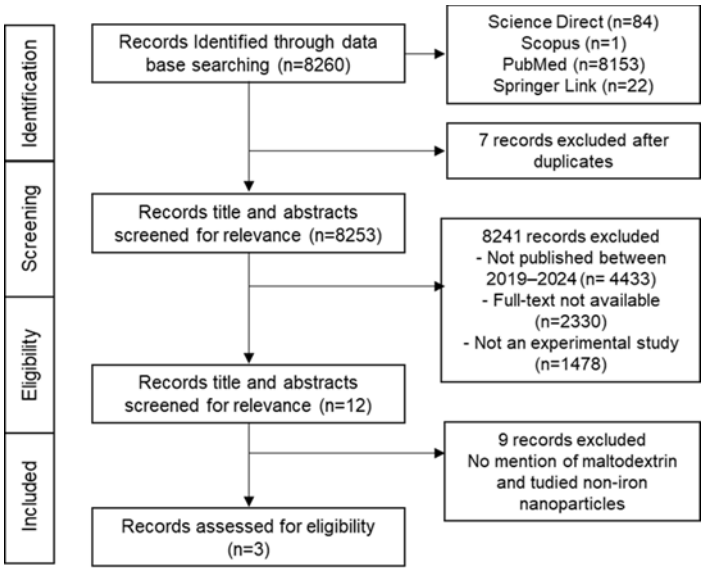

Figure 1. PRISMA-ScR Flow Diagram

Maltodextrin consistently functioned as an effective encapsulating agent across all studies. It acted as a water-soluble carrier, improving iron solubility, controlled release, and particle stability.[29] Technologically, maltodextrin enhanced bioaccessibility, reduced moisture content, promoted uniform particle morphology, and improved flowability when combined with excipients like hydroxypropyl methylcellulose (HPMC). These improvements contributed significantly to the stability and efficacy of iron nanoparticle formulations.[30,31]

Spray drying was the common technique for nanoparticle preparation, with maltodextrin paired with various co-excipients tailored to each study's application: inulin and caseinate, HPMC, and iron gluconate with vitamin B12.[25-27] The formulations yielded nanoparticles with favorable size, yield, and iron retention metrics. Notably, in vivo tests showed accelerated anemia recovery using maltodextrin-based dual encapsulation, highlighting its therapeutic potential alongside food fortification applications demonstrated in the other studies.[27]

Table 1. Summary of exploration of the role of maltodextrin in iron nanoparticle formulation

No	Article Title	Authors (Year)	Country	Research Objective	Kind of Products	Formulation Method	Nanoparticle Formulation	Function of Maltodextrin	Nanoparticle Characterization	In-vitro/In-vivo Bioavailability	Key Findings
1	Redesign of an Instant Legume Soup for Older Adults with Increased Micronutrients Bioaccessibility and Adequate Sensory Attributes by Using Encapsulation	Arazo-Rusindo et al. (2023)	Chile	To redesign instant legume soup for older adults with enhanced micronutrient bioaccessibility and sensory attributes using encapsulation technology	Food product	Spray drying of dispersion (iron) and emulsion (calcium and vitamin D3) using maltodextrin-inulin and maltodextrin-caseinate	- Type of iron: ferrous sulfate monohydrate - Formulation: The nanoparticle formulation involved creating iron dispersions and calcium/vitamin D3 emulsions using materials like ferrous sulfate, calcium lactate, vitamin D3, sunflower oil, and Tween-80, which were then encapsulated via spray drying with encapsulants such as maltodextrin (MD), inulin (IN), and calcium caseinate (CA) in various ratios	Used as a water-soluble encapsulating agent to form a protective matrix, enhancing stability and controlled release of micronutrients	Particle size: 200–300 nm; PDI <0.3; Zeta potential: -20 to -30 mV; Yield: 75–85%; Iron retention efficiency: 30–40%;	he proposed encapsulation process significantly increased the in-vitro micronutrient bioaccessibility, with an increase of 41 times for iron, 4.9 times for calcium, and 2.3 times for vitamin D3 at the particle level, as well as an increase of 20%, 29%, and 37% for these respective micronutrients in the developed lentil soup compared to the control product	Maltodextrin formed stable particles and enhanced iron bioaccessibility; potential for food fortification applications

2	Development and Characterization of Apple Pomace and Finger Millet-Based Pasta Enriched with Encapsulated Micronutrient	Kumari et al. (2023)	India	To encapsulate ascorbic acid and ferrous gluconate for enrichment into millet and apple-based pasta	Food product	Spray drying with 2.2–2.8% maltodextrin, 0.2–0.8% HPMC, and 1.5% iron gluconate core; Inlet temp: 120°C, Outlet temp: 80°C, Feed rate: 5 mL/min	- Type of iron: Iron-(II) gluconate (IG) - Formulation: The formulations for microencapsulated iron powder (IGP) consist of a fixed amount of 1.5% ferrous gluconate as the core material, with varying percentages of hydroxypropyl methylcellulose (HPMC) from 0.2% to 0.8% and maltodextrin (MD) from 2.8% to 2.2% as the wall materials	Used as wall material for encapsulation to maintain nutrient stability	Yield: 18.18–26.19%; Iron content: 40–51.5 mg/g; Solubility: >97%; Moisture content: 4.64–5.38%; Hygroscopicity: 16.47–23.57%; Color: bright yellow-green; Morphology: smooth to wrinkled; Uniform iron distribution	does not present in-vitro or in-vivo bioavailability data for its developed compound, it mentions that iron bioavailability can be enhanced by adding ascorbic acid and using HPMC as a wall material, and it references another study that has investigated the in-vitro bioavailability of microencapsulated iron	Maltodextrin improved solubility and reduced moisture content; HPMC reduced flowability and increased hygroscopicity; Encapsulation produced particles with uniform iron distribution and stable nutrients for functional pasta enrichment
3	Dual and Triple Encapsulated Iron Gluconate Speed Up Anemia Recovery in an Animal	Baldelli et al. (2023)	Canada	To investigate the effectiveness of dual and triple encapsulated iron gluconate with vitamin B12 in accelerating anemia recovery in an animal model	Phamaceutical product	Spray drying using HPMC as wall material and maltodextrin as bulk material	- Type of iron: Iron(II) gluconate hydrate - Formulation: consists of bioactive compounds like iron gluconate, vitamin B12, and others, encapsulated using hydroxypropyl methylcellulose (HPMC) as the wall material and maltodextrin as the bulk material, with HPMC and maltodextrin each at	Used as bulk material in combination with HPMC to improve stability and bioavailability	Average particle size: 2–5 µm (SEM); Uniform microspheric morphology; Homogeneous chemical distribution; No chemical structure changes (FTIR)	In-vitro studies showed a 25% increase in Caco-2 cell uptake with dual-encapsulated iron and vitamin B12, while in-vivo studies in anemic rats demonstrated hemoglobin recovery in just five days, significantly	Dual encapsulation (iron gluconate + vitamin B12) increased HepG2 cell viability by 17% and iron uptake by Caco-2 cells by 25%; In vivo, the fastest anemia recovery occurred in 5 days in rats fed with dual encapsulated

	9 wt% and the bioactive components totaling 7 wt%		faster than with encapsulated iron alone (15 days) or pure iron (21 days).	particles, compared to 15 and 21 days in single encapsulated and pure iron groups, respectively

Discussion

The three included studies all used spray-drying of maltodextrin-based formulations but with different co-carriers and conditions. Arazo-Rusindo et al. (2023) spray-dried aqueous and oil emulsions containing iron gluconate with maltodextrin–inulin or maltodextrin–caseinate matrices, while Kumari et al. (2023) used a maltodextrin/HPMC blend (2.2–2.8% MD with 0.2–0.8% HPMC) at an inlet/outlet of 120/80 °C (5 mL/min feed). Baldelli et al. (2023) also spray-dried iron–HPMC formulations with maltodextrin as a bulk carrier. In each case maltodextrin served as a film-forming, water-soluble matrix that stabilizes the mineral core.[32,33] Differences in wall composition and solids loading led to varied outcome, Arazo-Rusindo[25] reported high powder yields (75–85%) but modest iron retention (30–40%), whereas Kumari's[26] formulation gave only ~18–26% yield but retained high iron content (40–51.5 mg/g) in the powder. These contrasts suggest a trade-off between encapsulation environment (liquid soup vs. dry pasta matrix) and product recovery, which has also been noted by others (e.g. high MD levels can boost yield but sometimes at the expense of core retention).[33,34]

Spray drying is an effective, practical, and preferred microencapsulation method for micronutrients in this study, enabling enhanced protection, controlled release, and improved bioaccessibility of iron, calcium, and vitamin D3.[25,28,35] Spray-drying process parameters strongly influenced particle properties.[36,37] For example, increasing the inlet temperature tends to produce larger, drier particles and higher yields, at the risk of thermal degradation.[32,38] Consistent with this, Kumari's[26] relatively mild 120 °C inlet produced a powder with very low moisture (~4.6–5.4%) and excellent solubility (>97%), whereas Arazo-Rusindo[25] (using typical 140–180 °C conditions) achieved similarly low moisture (yielding stable matrices) but could sacrifice some micronutrient. Likewise, higher feed rates enlarge particle size and moisture.[32] Baldelli's[27] dual-encapsulated particles were reported as 2–5 µm spheres (SEM), much larger than Arazo-Rusindo's[25] 200–300 nm nanoparticles, likely reflecting differences in feed solids and atomization. In general, spray-drying at 150–200 °C (as reviewed by Piñón-Balderrama et al.(2025) minimizes water while preserving actives.[32,39] Solids concentration also matters: more concentrated feeds increase viscosity and yield larger, often irregular particles.[32,40] These formulation insights help explain the observed morphologies: Kumari noted smooth-to-wrinkled MD/HPMC particles, whereas Arazo-Rusindo's[25] nanoemulsions (PDI<0.3) formed uniform ~200–300 nm sphere.[32,42] Baldelli's[27] particles, though microscale, were still spherical and uniform by SEM, indicating well-controlled co-spray conditions.[39,42]

The critical nanoparticle characteristics align in part with known benchmarks. Arazo-Rusindo's[25] particles (200–300 nm, PDI <0.3) were well below the 500 nm threshold often cited for enhanced absorption, and their zeta potential (–20 to –30 mV) falls near the commonly cited ±30 mV stability threshold.[41,43-45] In contrast, Churio and Valenzuela

(2018) showed that larger (~0.9–1.0 µm) maltodextrin microparticles can still achieve 83–88% iron retention.[34] Encapsulation efficiency (iron retention) should ideally exceed 50% for effective fortification [19,46,47]. Indeed, most literature values are far higher for example, Kaul et al. (2022) reported ~90.7% iron retention in MD–starch spray-dried capsules, and Wang et al. (2017) achieved ~98.6% encapsulation efficiency with MD/CMC/caseinate. Recommended targets thus include size <500 nm for bioaccessibility, zeta potential |≥30 mV| for colloidal stability, and high encapsulation efficiency (often >80%).[41,44] In this review, moisture <6% was generally met (Kumari's[26] 4.6–5.4%), consistent with food-powder norms, while Kumari's[26] >97% solubility and low hygroscopicity (≤6% moisture and moderate hygroscopicity ~16–24%) indicate good reconstitution. Notably, Kumari et al. (2023) and Baldelli et al. (2023) did not report zeta-potential, but Arazo-Rusindo's[25] values (–20 to –30 mV) are on the edge of recommended stability.[44] Overall, the reported values largely fall within desirable ranges, though Arazo-Rusindo's[25] iron retention (30–40%) was lower than expected and suggests incomplete encapsulation or losses during spray drying.

Comparing across studies highlights some inconsistencies and trade-offs. Arazo-Rusindo's[25] high yield but low iron retention contrasts with Kaul (2022) and Churio (2018) who achieved ~80–90% retention.[34,48] This likely reflects Arazo-Rusindo's[25] complex emulsion matrix (soup) versus simpler dry systems; losses of iron in the aqueous phase or during emulsification may account for the modest 30–40% retention. In turn, Kumari's[26] low yield (~20%) but high nutrient load (40–51 mg/g) suggests that the MD/HPMC matrix was efficient at loading but that much feed was not recovered (maybe due to stickiness or cyclone losses). The addition of HPMC (as in Kumari[26] and Baldelli[27]) increased powder hygroscopicity, in line with previous observations that hydrocolloids raise moisture uptake. Zeta potentials, where reported, were moderate: Arazo-Rusindo's[25] –20 to –30 mV is lower than some ideal values but matches other maltodextrin systems (Abbasi *et al.*[41] (2022) found ~–30 mV needed for stability). Particle size outcomes were most divergent: Arazo-Rusindo's[25] 200–300 nm vs. Baldelli's[27] 2–5 µm, underscoring how wall material and method (nanospray vs. conventional) dominate size. These differences reflect known effects adding more polymer (HPMC, alginate, etc.) often yields larger particles, and denser solids give more microspheres.[50,51] No major contradictions appear beyond these expected trade-offs, and all studies noted uniform, spherical particles (smooth surface typical for MD matrice).[33]

These findings have practical implications. Formulators should target the submicron range and stable zeta potenstial to maximize bioavailability.[41,44] Given that maltodextrin enhances solubility and protection of actives, increasing MD proportion (up to its glass transition limit) will improve particle stability and yield, but mixing with other polymers (HPMC, CMC, proteins) can tailor release or protect against oxidation.[33] For instance, Piñón-Balderrama et al (2020). showed that MD-alginate blends produce more stable iron

microcapsules. In practice, inlet temperatures of ~150–180 °C (yielding <6% moisture) are recommended, and feeding rates should be optimized to avoid excessive particle growth.[32] Future research should systematically explore MD dextrose equivalent, MD/auxiliary ratios, and nozzle technologies (including nano-spray drying) to control size and EE. Importantly, in vivo bioavailability trials beyond the rat model of Baldelli[27] are needed to link these particle metrics to actual iron absorption. Standardizing measurements (e.g. using unified definitions of yield and retention, or simulating gastrointestinal release as Churio[34] did) will also help reconcile results.

Ultimately, these studies confirm maltodextrin as a versatile matrix for iron micro/nanoparticles, though optimizing parameters is crucial for stability and bioactive retention.[25-27] Iron nanoparticles show superior bioavailability due to their size and surface area, enhancing interaction with intestinal mucos .[52] In rats, absorption occurs via enterocyte endocytosis, bypassing regulatory mechanisms that limit ionic iron uptake, resulting in more efficient systemic absorption. Integrating these insights with microencapsulation advances highlights the potential for iron nanoparticle formulations that maximize bioavailability while reducing side effects.[53,54] Refining maltodextrin-based encapsulation processes with understanding of absorption mechanisms provides a foundation for advancing iron supplementation strategies.[34,48]

Conclusions

In conclusion, maltodextrin plays a crucial role in iron nanoparticle formulation in the some products such as food fortification and pharmaceutical applications by acting as a water-soluble encapsulating agent that enhances particle stability, solubility, and controlled release. Its include for some iron forms such as ferrous sulfate, ferrous fumarate, and ferric pyrophosphate. Its application through spray-drying techniques, often in combination with co-polymers like HPMC or caseinate, has been shown to produce nanoparticles with favorable characteristics, including particle sizes below 500 nm, zeta potentials within the ±20–40 mV range, and encapsulation efficiencies exceeding 50%. However, differences in formulation methods such as inlet temperature, feed rate, and wall material composition contribute to variability in outcomes like yield, moisture content, and iron retention. These parameters must be carefully optimized to ensure stability, bioavailability, and controlled release of the encapsulated iron, making spray-drying a versatile and scalable approach for iron fortification in food and pharmaceutical applications. While Maltodextrin shows promise for micronutrient delivery, limitations include insufficient in vivo studies and non-standardized metrics across food matrices. Current evidence lacks data on long-term safety. For anemia treatment, maltodextrin-encapsulated iron supplementation can enhance bioavailability and reduce side effects by improving stability and controlled release. Programs should

combine this system with dietary diversification to target iron absorption. Implementation requires evidence-based dosing based on age, physiological status, and anemia severity. Clinical trials are needed to validate this approach. evidence-based interventions.

Conflict of interest

The authors declare no conflict of interests regarding the publication of this article.

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Author's contribution

R.A.: Conceptualization, literature search, study screening and selection, data extraction, formal analysis, interpretation of findings, drafting of the manuscript, and final approval of the version to be published;
D.I.: Conceptualization, methodological supervision, interpretation of findings, critical revision of the manuscript for important intellectual content, correspondence, and final approval of the version to be published;
Y.H.S.: Supervision, interpretation of findings, critical revision of the manuscript, and final approval of the version to be published.

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