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Faculty of Technology and Technical Sciences - Veles

Book of proceedings of the 1st International Scientific Conference - Food Science, Nutrition, Innovative Technologies and Sustainability

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MAGNESIUM AND NUTRITIONAL HEALTH: NUTRITIONAL STRATEGIES TO REDUCE MAGNESIUM DEFICIENCY WITH FOOD FORTIFICATION

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Abstract
Magnesium (Mg), the fourth most abundant cation in the human body, plays a vital role in numerous physiological processes, including bone mineralization, protein synthesis, neuromuscular function, and cardiovascular regulation. Mg deficiency or hypomagnesemia, is commonly observed in clinical settings particularly among critically ill patients where it correlates with increased morbidity and prolonged hospitalization. Symptoms of deficiency range from muscle spasms and tremors to cardiovascular irregularities and neurological disturbances. Moreover, low Mg levels are associated with chronic diseases such as type 2 diabetes, osteoporosis, preeclampsia, migraine, and asthma. To address Mg deficiency at the population level, biofortification has gained attention as a sustainable approach to enhance Mg content in foodproducts and improve human uptake. Food fortification involves the addition of essential micronutrients to widely consumed staples to enhance their nutritional quality. This review aims to explore the role of food fortification as a critical public health strategy to combat global micronutrient deficiencies people worldwide, with special reference to magnesium. Also, explores the evolution of food fortification, and public health impacts of food fortification, emphasizing its success in mitigating health conditions. This review examines current knowledge on magnesium deficiency and fortification strategies, aiming to support evidence-based micronutrient policy and public health interventions.As modern research continues to highlight the diverse benefits of this essential mineral, ensuring adequate magnesium intake remains a priority, reinforcing the role of fortification as a key strategy to combat widespread deficiencies and promote health.

Keywors: food fortification, magnesium deficiency, health benefits

1. Introduction

Magnesium is a vital cofactor in over 300 enzyme systems, which regulate protein synthesis, muscle and nerve function, blood glucose, and blood pressure. It is required for DNA and RNA synthesis, energy production, and the structural stability of proteins, nucleic acids, and mitochondria (Gröber et al., 2015). Magnesium deficiency is often linked to poor diet, absorption issues, kidney disease, alcoholism, or drug interactions can increase the risk of chronic diseases such as diabetes, cardiovascular disease, Alzheimer's, hypertension, and migraines.Assessment of magnesium status is difficult, as serum levels are most commonly measured but do not always reflect body stores. A combination of serum magnesium, urinary excretion, and dietary intake gives a more accurate picture. Good dietary sources include vegetables, whole grains, cocoa, nuts, and seeds, though absorption can be reduced by phytates, oxalates, and some fibers (Fiorentini et al., 2021). Organic supplement forms are better absorbed than inorganic ones, and smaller divided doses are more effective. Excess magnesium, usually from supplements may cause diarrhea, and magnesium supplements should be used with caution in individuals with kidney disease (Elgar, 2022). Despite these challenges, magnesium supplementation remains an important strategy for maintaining optimal health and preventing deficiency-related disorders.Since suboptimal magnesium intake is common, nutritional strategies such as food fortification have been proposed to reduce deficiency at the population level (Bhagwat et al., 2014). Fortifying staple foods (e.g., flour, cereals, dairy products and beverages) with magnesium can help improve daily intake, especially in groups with higher needs or limited access to magnesium-rich foods. Combined with dietary education and balanced nutrition, food fortification represents a cost-effective and sustainable approach to support magnesium status and overall health.

2. Literature Review

Magnesium is an essential electrolyte for living organisms and is the fourth most abundant mineral in the human body. People should consume magnesium regularly to prevent magnesium deficiency, but since the recommended daily intake for magnesium varies, some studies claim that it is difficult to define exactly what the exact optimal intake should be (Gröber et al., 2015). Based on the many functions of magnesium in the human body, it plays an important role in the prevention and treatment of many diseases.

2.1 Functions of Magnesium

Magnesium is an essential cofactorfor various enzymes involved in glycolysis and the Krebs cycle, and mitochondrial magnesium is also claimed to play an important role in the regulation of function. As such, magnesium is essential for cellular energy production. Magnesium acts as a calcium antagonist, for example in neuromuscular and cardiac function, and helps maintain ion gradients. Magnesium is involved in the synthesis of DNA, RNA, and proteins and is an essential component in the structure of DNA and RNA. Magnesium also serves as a structural component in bones and teeth.

Magnesium is essential for more than 300 metabolic reactions, playing a key role in energy production by supporting ATP-dependent processes, including the breakdown and utilization of carbohydrates, proteins, and fats, as ATP primarily exists in complex with magnesium (MgATP). It is required for enzyme activation such as mitochondrial ATP synthesis, Na^+/K^+-ATPase, hexokinase, creatine kinase, adenylate cyclase, phosphofructokinase, and insulin receptor tyrosine kinase activity. Acting as a natural calcium and NMDA receptor antagonist, magnesium regulates calcium influx, muscle contraction and relaxation, neurotransmitter release, action potential conduction, and stabilization of membrane physiology (Gröber, 2015). In the cardiovascular system, it supports heart function, potassium regulation in myocardial cells, vasodilation, stress protection, and reduced platelet aggregation. Magnesium also contributes to membrane function by regulating electrolyte flux, active ion transport, and cell adhesion and migration. Structurally, it is a component of bones, enzyme complexes, mitochondria, proteins, polyribosomes, and nucleic acids. Additionally, it aids nutrient metabolism by activating and utilizing vitamin D, B vitamins, and glutathione(Swaminathan, 2003;Gröber, 2009; Rude et al., 2012).

2.2 Magnesium as a food and dietary supplement

Magnesium is part of the chlorophyll molecule in plants, which gives plants their green color. Therefore, vegetables are one of the best sources of magnesium in the diet. Nuts and seeds, legumes, and whole grains are other good sources, although these foods are also high in phytates, which interfere with magnesium absorption. Nuts and seeds have little saturated fat but are rich in healthy fats (MUFAs and PUFAs, including omega-3 and omega-6). They are also good sources of vitamin E and magnesium (Siriwardhana et al. 2012).

The Recommended Dietary Allowance (RDA) for magnesium varies by age, sex, and physiological status, starting from 30 mg for infants and increasing up to 420 mg for adult men and 320 mg for adult women, with slightly higher needs during pregnancy and lactation (IOM, 1997; Alawi et al., 2018). EFSA set Adequate Intakes (AIs) for magnesium, not Population Reference Intakes (PRIs), because average requirements couldn't be established for magnesium. For adults, an AI for magnesium is set at 350 mg/day for men and 300 mg/day for women, and these values are based on observed intakes in healthy EU populations. AIs also exist for children and adolescents, with ranges depending on age and sex (EFSA, 2017). Magnesium can be obtained from foods or supplements, which may be prescribed in cases of deficiency. Supplements support bone health by aiding calcium absorption, regulate muscle and nerve function, and help maintain cardiovascular health by stabilizing heart rate and blood pressure. While beneficial, magnesium supplementation should always be guided by a healthcare professional to ensure safe and appropriate use.

2.3 Magnesium deficiency, treatment and prevention of diseases

Severe hypermagnesemia (magnesium intoxication) is rare, usually occurring only in advanced kidney or liver failure (Tokmak et al., 2008;Vierling et al., 2013). In contrast, magnesium deficiency is common, especially with aging. Early symptoms are nonspecific loss of appetite, nausea, and fatigue while severe deficiency causes tremors, cramps, tetany, seizures, and cardiac arrhythmias. Hypomagnesemia often appears with low potassium or calcium and is linked to alcoholism, poorly controlled diabetes, malabsorption, endocrine disorders, hyperthyroidism, and certain drugs (e.g., diuretics, proton pump inhibitors, antibiotics, chemotherapy). Additional studies have shown that magnesium deficiency exacerbates potassium-mediated arrhythmias, especially in the presence of digoxin intoxication (Gröber, 2006; Gröber, 2009; Classen et al., 2012).Magnesium deficiency is common in both type 1 and type 2 diabetes, affecting 13–48% of patients due to poor intake and renal loss (Palmer & Clegg, 2015; Ramadass et al., 2015). Magnesium is vital for insulin function and glucose metabolism, and low intake is linked with higher diabetes risk. A meta-analysis showed that every 100 mg/day increase in magnesium lowered type 2 diabetes risk(Saito,2004). Magnesium may also reduce diabetes-related complications such as kidney disease, blindness, heart attack, stroke, depression, and dementia (Touyz, 2004;Vormann, 2014).

Low magnesium is associated with hypertension and atherosclerosis (Kisters, 2005). Deficiency raises blood pressure through effects on calcium, angiotensin II, and vascular tone. Clinical studies show magnesium supplementation (240–960 mg/day) lowers systolic and diastolic blood pressure, especially in hypertensive patients, and reduces cardiovascular risk factors (Aydin, 2010).According to another study oral magnesium sulfate (600 mg daily) has been shown to reduce migraine frequency, while intravenous magnesium (1000 mg) is effective for treating acute migraine attacks, comparable to standard medications (Bigal et al., 2002). Ionized magnesium levels in the brain are reduced in Alzheimer's disease (AD). A large number of researchers claim that low magnesium intake impairs memory, while supplementation and magnesium citrate-enriched diets improve cognitive performance in patients with dementia(Bardgett et al. 2005; Barbagallo et al., 2011; Cherbuin et al., 2014).

Magnesium is essential for bone structure and vitamin D metabolism. Magnesium is intricately involved in vitamin D metabolism; magnesium is required for the synthesis and conversion of vitamin D, while vitamin D is also important for magnesium absorption (Eremet al., 2019). Low intake is linked to reduced bone density and higher fracture risk. Clinical studies show supplementation (as magnesium carbonate)as (250–750 mg/day in adults, ~300 mg/day in children) improves bone density and mineral content, particularly in postmenopausal women and individuals with deficiency (Saito, 2004; Euser&Cipolla, 2009; Castiglioni et al., 2013; Zheng, 2014;Farsinejad-Marj et al., 2016; Veronese, 2017).Magnesium supplements are generally well tolerated but may cause gastrointestinal symptoms (diarrhea, nausea, vomiting), and overdose especially intravenously can lead to serious effects such as hypotension, arrhythmia, respiratory depression, coma, and death (Gröber et al., 2015). Magnesium salts (hydroxide, carbonate, trisilicate) are widely used in antacids for indigestion, reflux, gastritis, and ulcers, but long-term use is discouraged due to side effects and drug interactions. Factors such as chronic diarrhea, pancreatic insufficiency, celiac disease, alcoholism, and inflammatory bowel disease can further impair magnesium absorption (Marta et al., 2022).

2.4 Nutritional Assessment

Nutritional assessment involves the systematic evaluation and interpretation of anthropometric, biochemical, clinical, and dietary data to determine the nutritional status of an individual or population group, identifying whether they are well-nourished, at risk, or undernourished (Eastwood, 2003). A commonly used framework for conducting such assessments is the ABCD approach**,**which encompasses four primary components:

A) Anthropometric measurements (e.g., body weight, height, BMI, skinfold thickness),

B) Biochemical analyses (e.g., blood and urine tests to detect micronutrient deficiencies),

C) Clinical evaluation (e.g., identification of physical signs associated with nutrient deficiencies), and

D) Dietary assessment (e.g., food frequency questionnaires, 24-hour recalls, or dietary records to estimate nutrient intake).

The assessment of magnesium status is important for the study of diseases associated with chronic deficiency.Anthropometry involves measuring the physical dimensions of the body to assess nutritional status. Although it does not directly measure magnesium levels, it provides valuable information about overall health and nutritional status, which may indirectly indicate magnesium deficiency.Although magnesium status has been extensively studied, there is still no laboratory test that provides a simple, rapid, and accurate assessment of total body magnesium levels (Nielsen, 2024). In clinical practice, the measurement of total or ionized serum magnesium remains the most commonly used and accepted indicator serum magnesium< 0.75 mmol/L indicates severe deficiency, while borderline values (0.75–0.85 mmol/L) may require a loading test, considered the gold standard (Arnaud, 2008). The loading test involves administering an intravenous or oral magnesium load, then collecting urine over 24 hours to measure magnesium excretion. However, this test is time-consuming and unsuitable for patients with impaired renal or gastrointestinal function. Muscle and bone magnesium levels may offer better indicatorsbut are limited by the need for invasive procedures. Discrepancies among cellular magnesium measurements (e.g., total vs. ionized Mg) further highlight the need for standardized protocols and continued research. However, the diagnostic accuracy of total or ionized serum magnesium—currently the most commonly used indicator—can be improved by integrating additional parameters such as dietary magnesium intake and 24-hour urinary magnesium excretion. Cross-validation of serum magnesium concentrations with these complementary measures could enhance the interpretation of magnesium status and allow for a more accurate classification of deficiency or adequacy (Nielsen, 2024).

3. Nutritional strategies and food fortification

To address theissue of magnesium insufficiency, public health strategies commonly include the promotion of magnesium-rich diets, targeted supplementation, and food fortification initiatives.Food fortification strategies introduce essential vitamins and minerals into the food supply via processing, preparation, and even agricultural enhancement techniques, aiming to reduce the burden of micronutrient deficiencies (Olson et al., 2021).

The effects of magnesium salt fortification on the properties of dairy products have been reported in a limited number of studies (Cueva &Arvana, 2008; Pawlos et al., 2016; Sajnar et al., 2017). Among fermented dairy products, yogurt remains the most widely consumed, prompting manufacturers to diversify product offerings in response to consumer demand.Several studies have investigated the influence of magnesium fortification on yogurt quality.Szajner et al. 2018 examined the impact of magnesium L-lactate hydrate on acidity, texture, viscosity, and microbial activity in non-fat yogurts produced using three different starter cultures. Their findings suggest that fermented dairy products are suitable vehicles for magnesium enrichment, particularly when aiming to enhance the viability and metabolic activity of probiotic strains such as *Bifidobacterium Bb-12* (Szajner et al., 2018; Szajner et al., 2019). In this context, the effects of various organic magnesium salts, namely magnesium D-gluconate, L-lactate, acetate, and others, were evaluated in terms of their influence on physicochemical parameters, organoleptic attributes, texture, and the survival of *Bifidobacterium Bb-12*. Among the tested compounds, magnesium D-gluconate was found to be the most effective stimulator of probiotic growth. Fortification with magnesium also significantly influenced textural properties, notably increasing hardness and decreasing brightness of the fermented milk. Organoleptic evaluation further confirmed that magnesium D-gluconate produced the most favorable results in terms of sensory acceptability, making it a promising candidate for dairy-based magnesium fortification strategies.Similar findings are reported in a study evaluating the fortification of yogurt with six different magnesium compounds (magnesium acetate, L-pidolate, chloride hexahydrate, L-lactate hydrate, bisglycinate, and D-gluconate hydrate) and their effects on fermentation kinetics, acidity, syneresis, texture, and color (Szajner et al., 2016). All compounds were added at a concentration of 30 mg Mg per 100 g of milk and the results indicated that magnesium enrichment did not inhibit the fermentation process and generally improved water retention by reducing syneresis. However, the impact on textural and visual properties varied depending on the type of magnesium salt used. The findings confirm that magnesium fortification is technologically feasible, and among the evaluated salts, magnesium D-gluconate hydrate appears to be the most suitable for maintaining yogurt quality. In contrast, other compounds induced noticeable changes in hardness, adhesiveness, and color. Furthermore, Znamirowska et al. (2019) investigated the fortification of fermented goat's milk using various organic magnesium salts. The study aimed to assess the effects on fermentation, acidity, texture, and sensory characteristics. Results demonstrated that magnesium addition did not inhibit fermentation and generally improved the nutritional profile of the product. Although some salts slightly influenced acidity and texture, the overall quality remained acceptable. These findings support the potential of organic magnesium salts as suitable fortifying agents for functional goat milk-based dairy products, without compromising product integrity.

Recent research has demonstrated that Chihuahua cheese can serve as an effective vehicle for magnesium fortification (Rojo-Gutiérrez et al., 2022). In the study, various concentrations of magnesium chloride ($MgCl_2 \cdot 6H_2O$) were added to milk during pasteurization, resulting in increased magnesium content in the final cheese product (up to ~2,957 mg/kg). The optimal level of fortification was identified as 10.8 g $MgCl_2 \cdot 6H_2O$ per kg of milk, yielding a product that complied with quality standards and maintained organoleptic characteristics comparable to traditional Chihuahua cheese. At this fortification level, a daily intake of three servings (84 g) of cheese delivers approximately 148 mg of magnesium, covering roughly 35% of the recommended daily intake (RDI) for men and 46% for women. Higher concentrations ($\geq$16.4 g/kg) were associated with undesirable bitter-acidic flavors and excessive softening of texture.

Magnesium is frequently included in the formulation of fortified breakfast cerealsand other fortified foods. Fortification of cereal-based products with magnesium may be implemented through various strategies, including: the addition of premixed magnesium compounds during flour milling; the use of agronomic techniques; or direct incorporation of magnesium during the stages of food processing (Cobalchin et al., 2021; White&Broadley, 2009).

In general, although conventional food fortification remains a cost-effective strategy, it is often constrained by challenges related to affordability, infrastructure, regulatory frameworks, and consumer acceptance. As a complementary approach, food-to-food fortification—utilizing locally available, nutrient-dense foods such as legumes, leafy vegetables, and small fish—has gained attention for its potential to enhance dietary diversity and accessibility. Evidence from past initiatives suggests that the success of fortification programs relies on robust policy support, active collaboration with the food industry, and sustained community engagement. Together, conventional and food-to-food fortification represent essential strategies in addressing hidden hunger (Chadare et al., 2019).

4. Conclusion

Magnesium is an essential mineral that regulates many physiological processes and is vital for overall health. Its adequate intake supports muscle and nerve function, regulates blood glucose and blood pressure, and prevents chronic diseases such as diabetes and cardiovascular disorders. Deficiency is widespread and can cause cramps, fatigue, irregular heartbeat, and increase the risk of serious health conditions. Modern diets often fail to meet magnesium needs, making food fortification an important strategy. Fortification through dairy and fermented products with bioavailable magnesium salts and probiotics improves stability, absorption, and consumer acceptance. Integrating magnesium fortification into public health policies is a cost-effective and sustainable way to reduce deficiencies and improve population health.

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