

Review Article

Beneficiary Role of Zinc and Iron Fortification for Foods in Under-5 Children: Supporting & Enhancing Cognitive and Physical Development During the Preschool Years

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Abstract

Micronutrient deficiencies, particularly iron and zinc deficiencies, represent a significant global public health challenge, especially among children under five years of age in low- and middle-income countries. Early childhood is a critical period for brain development, physical growth, and immune maturation, all of which depend on adequate micronutrient intake. Iron deficiency is the most common cause of anemia worldwide and is strongly associated with impaired cognitive development, delayed psychomotor performance, reduced attention span, and poor learning capacity. Zinc deficiency contributes to growth retardation, compromised immune function, increased susceptibility to infections, and elevated risks of morbidity and mortality in young children. Food fortification with iron and zinc has emerged as a cost-effective, scalable, and sustainable intervention to address these deficiencies at the population level. Fortifying commonly consumed staple foods and complementary foods allows for widespread micronutrient delivery without requiring major dietary behavior changes. Evidence from randomized controlled trials and national nutrition programs indicates that iron and zinc fortification can improve hemoglobin concentrations, reduce anemia prevalence, support linear growth, and enhance cognitive and motor development during the preschool years. This review evaluates the role of iron and zinc fortification in improving cognitive and physical development among under-five children, focusing on the crucial preschool period. Findings from clinical studies, large-scale fortification initiatives, and World Health Organization (WHO) guidelines are synthesized to highlight the physiological benefits of these micronutrients. In addition, key implementation challenges—such as micronutrient bioavailability, fortification selection, program coverage, quality control, and monitoring—are discussed. The review underscores the importance of well-designed fortification strategies and strong policy support in combating hidden hunger and improving child health outcomes globally.

Keywords

Micronutrient Deficiency, Under-five Children, Iron Fortification, Zinc Fortification, Food Fortification, Cognitive Development, Preschool Nutrition, Hidden Hunger

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1. Introduction

The first five years of life are crucial for a child's physical growth and brain development. During this period, nutritional deficiencies—particularly those involving iron and zinc—can have long-lasting effects on cognitive abilities, immunity, and motor skills.

Iron is essential for oxygen transport, energy metabolism, and brain function. Its deficiency leads to iron-deficiency anemia, which is associated with impaired neurodevelopment, lower IQ scores, and reduced attention span. Zinc, on the other hand, is vital for cell growth, immune function, and neurogen-

esis. Zinc deficiency has been linked to stunted growth, delayed motor development, and increased susceptibility to infections [1].

Despite global efforts, more than 30% of children under five in low- and middle-income countries (LMICs) suffer from iron and/or zinc deficiencies. Traditional supplementation strategies have limitations due to poor adherence, supply chain issues, and cost. Food fortification—adding micronutrients to widely consumed foods—offers a sustainable, population-level intervention to address these gaps.

2. Discussion

2.1. Prevalence and Consequences of Deficiencies [2]

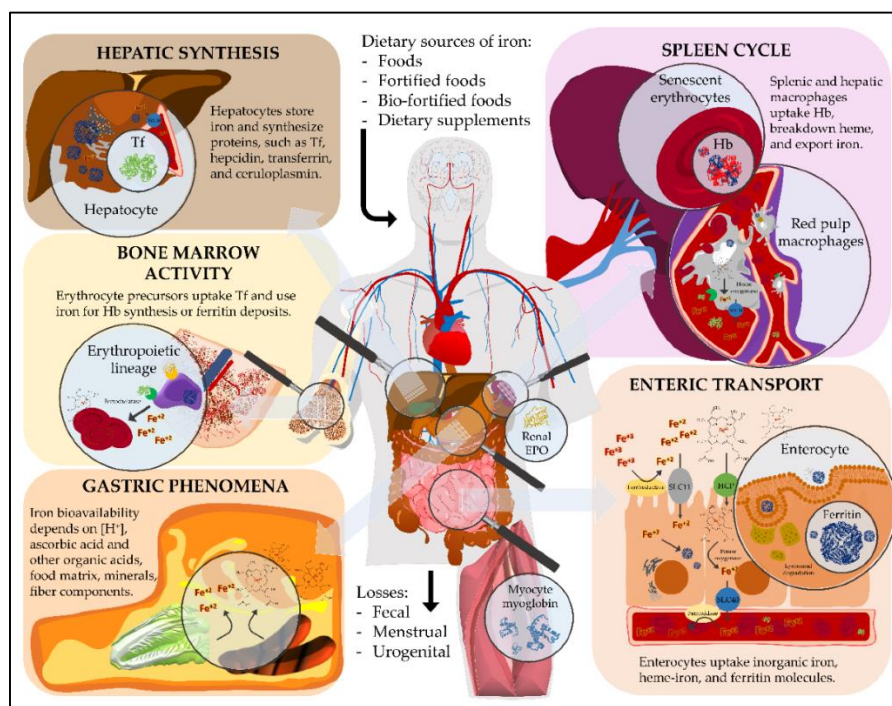


Figure 1. Biological pathways of iron [3].

According to the World Health Organization (WHO):

- 1) Iron deficiency affects over 40% of children under five globally.
- 2) Zinc deficiency is prevalent in more than 20% of young children, particularly in South Asia and Sub-Saharan Africa.

Consequences include:

- 1) Poor cognitive development
- 2) Reduced school performance
- 3) Impaired motor and social development
- 4) Weakened immunity and higher infection rates

2.2. Role of Iron and Zinc in Development

Iron:

- 1) Crucial for hemoglobin production.
- 2) Supports myelination and neurotransmitter synthesis.
- 3) Iron deficiency during critical periods may result in irreversible brain damage.

Zinc:

- 1) Vital for DNA synthesis and cell division.
- 2) Facilitates synaptic plasticity and memory formation.
- 3) Deficiency impairs neuropsychological development

and immune response.

2.3. Mechanism of Fortification [4]

Fortification involves adding nutrients to staple foods such as:

- 1) Wheat flour
- 2) Rice

- 3) Maize flour
- 4) Milk
- 5) Complementary weaning foods

Fortified foods are formulated to:

- 1) Provide up to 50–100% of recommended daily intake.
- 2) Use bioavailable forms (e.g., ferrous sulfate, zinc oxide).
- 3) Maintain taste, texture, and shelf life.

2.4. Evidence from Studies [5]

Table 1. Evidence from Randomized Trials and Meta-Analyses on Iron and Zinc Fortification in Preschool-Aged Children.

Study	Country	Intervention	Key Outcomes
Bhutta et al., 2013	Multiple LMICs	Zinc and iron-fortified cereal	↑ height-for-age, ↓ infections
Dewey et al., 2001	Guatemala	Iron-fortified milk	↑ motor development, ↑ hemoglobin
Mayo-Wilson et al., 2014	Global meta-analysis	Micronutrient powders	↑ cognitive scores, ↓ anemia

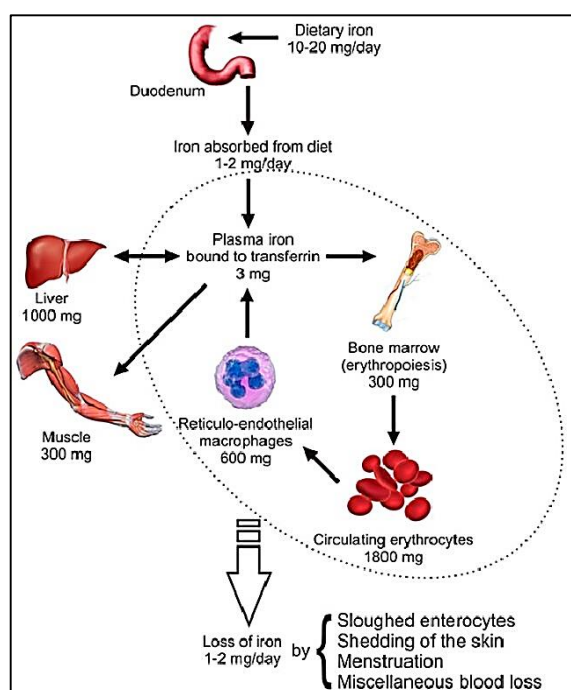


Figure 2. Roles of Iron^{+} in a Human body [6].

2.5. Impact on Cognitive Development

- 1) *Language development:* Iron-fortified foods have been shown to improve vocabulary acquisition in toddlers.
- 2) *Memory and attention:* Zinc and iron improve short-term memory, processing speed, and attentional control.

- 3) *School readiness:* Early fortification is linked with better preschool performance.

2.6. Impact on Physical Growth and Immunity [7]

- 1) Zinc improves linear growth and reduces stunting.
- 2) Iron improves weight gain, hemoglobin levels, and reduces the prevalence of anemia.
- 3) Combined interventions reduce diarrheal diseases, respiratory infections, and skin conditions.

2.7. National Programs and Case Studies

- 1) *India:* Under the POSHAN Abhiyaan, micronutrient-fortified rice and take-home rations are distributed in Anganwadi centers.
- 2) *Nigeria:* Fortified flour and oil programs have helped reduce iron deficiency in children by 15%.
- 3) *Bangladesh:* Home fortification with multiple micronutrient powders has reached over 5 million children.

2.8. Challenges in Implementation [8]

- 1) *Cost:* Initial costs of fortification technology and distribution.
- 2) *Regulatory framework:* Need for enforcement of quality and safety standards.
- 3) *Bioavailability:* Some compounds interact poorly with food matrices.
- 4) *Cultural acceptance:* Some parents resist fortified products due to color or taste changes.

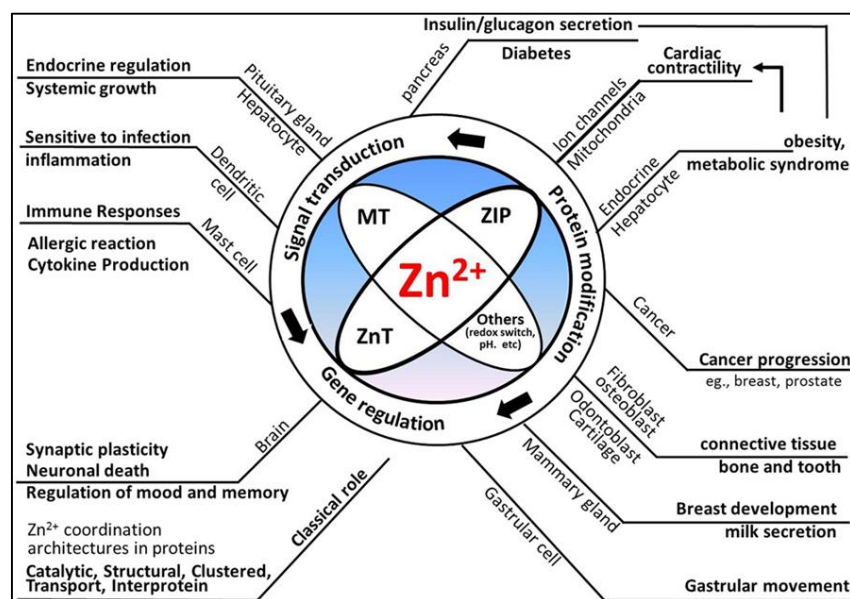


Figure 3. Roles of Zn^{2+} in a biological system [9].

2.9. The Role of Policy and Partnerships

Successful fortification programs require:

- 1) Government leadership and mandatory fortification legislation.
- 2) Public-private partnerships with food manufacturers.
- 3) Consumer education and monitoring frameworks.
- 4) International support from organizations like WHO, UNICEF, and GAIN.

3. Relevant Data and Statistics [10]

Global Prevalence in Under-5 Children:

- 1) Iron Deficiency: 40%
- 2) Zinc Deficiency: 25%
- 3) Anemia Prevalence: 43%
- 4) Stunting: 22% (linked to zinc deficiency)
- 5) Wasting: 6.7% globally (UNICEF, 2024)

Estimated Benefits of Fortification (per 100 children):

- 1) 35 show improved cognition
- 2) 30 improve physical growth
- 3) 20 have reduced infections
- 4) 15 avoid anemia onset

4. Fortification as a Public Health Strategy in Low and Middle-income Countries [11]

Food fortification with essential micronutrients such as iron and zinc has emerged as one of the most effective public health nutrition strategies in low- and middle-income countries (LMICs), where dietary diversity is often limited and the

burden of micronutrient deficiencies remains high. Unlike supplementation programs, which require active compliance and regular health system contact, fortification reaches large segments of the population passively through commonly consumed staple foods. This population-wide approach is particularly beneficial for under-5 children, who are highly vulnerable to nutritional deficiencies during critical periods of growth and neurodevelopment. Evidence suggests that fortification programs can significantly reduce the prevalence of anemia, stunting, and zinc deficiency when implemented at scale with appropriate quality control measures. In LMICs, fortified foods such as wheat flour, rice, edible oils, and complementary weaning foods serve as practical delivery vehicles for essential micronutrients. Moreover, fortification has been shown to be cost-effective, with high benefit-to-cost ratios compared to other nutrition interventions. The World Bank and WHO estimate that every dollar invested in fortification yields multiple dollars in economic returns through improved productivity, reduced healthcare costs, and enhanced cognitive potential. However, successful implementation requires strong governance, regulatory oversight, and continuous monitoring to ensure appropriate dosing, bioavailability, and safety. Without these safeguards, the intended health benefits may not be fully realized. Thus, fortification should be integrated into national nutrition policies alongside maternal and child health programs, social safety nets, and food security initiatives to achieve sustainable improvements in child health outcomes.

5. Safety, Bioavailability, and Monitoring of Iron and Zinc Fortification [12]

Ensuring the safety and bioavailability of iron and zinc in fortified foods is essential for maximizing health benefits while minimizing potential risks. Different forms of iron and

zinc vary in their absorption, stability, and interaction with food components such as phytates, calcium, and polyphenols. Compounds like ferrous sulfate, ferrous fumarate, and zinc oxide are commonly used due to their balance between cost, bioavailability, and minimal sensory changes in foods. However, inappropriate formulation or excessive intake may increase the risk of gastrointestinal side effects, oxidative stress, or interference with the absorption of other micronutrients. Therefore, fortification programs must adhere strictly to internationally recommended levels based on age-specific dietary requirements and existing nutritional status. Continuous monitoring and evaluation systems are critical to assess program effectiveness, detect adverse effects, and ensure compliance with regulatory standards. Biomarkers such as hemoglobin concentration, serum ferritin, and plasma zinc levels provide valuable insights into population-level nutritional impact. Additionally, food quality testing at production and retail levels helps maintain consistency and consumer trust. In many LMICs, weak regulatory enforcement and limited laboratory capacity pose challenges to effective monitoring. Strengthening national food safety authorities, investing in laboratory infrastructure, and training technical personnel are essential components of sustainable fortification programs. Community education also plays a role in addressing misconceptions and improving acceptance of fortified foods. When safety, quality, and monitoring are adequately addressed, iron and zinc fortification remains a safe and powerful tool for improving child health and development [13, 14].

6. Long-term Developmental and Societal Benefits of Early Micronutrient Fortification [15, 16]

The benefits of iron and zinc fortification in early childhood extend far beyond immediate health outcomes, contributing to long-term human capital development and societal progress. Adequate micronutrient intake during the first five years of life supports optimal brain development, laying the foundation for learning capacity, emotional regulation, and social functioning. Studies have demonstrated that children who receive sufficient iron and zinc during early childhood perform better in school, exhibit improved attention and memory, and have higher educational attainment later in life [17]. These cognitive advantages translate into increased productivity, higher earning potential, and reduced intergenerational cycles of poverty. From a societal perspective, improved childhood nutrition contributes to a healthier workforce, reduced healthcare expenditure, and enhanced national economic growth. In countries like Bangladesh, where a significant proportion of the population is young, investing in early-life nutrition through fortification represents a strategic investment in the nation's future [18]. Furthermore, fortification aligns closely with global development priorities, including the Sustainable Development Goals related to health (SDG 3), zero hunger

(SDG 2), quality education (SDG 4), and reduced inequalities (SDG 10). To fully realize these long-term benefits, fortification programs must be sustained, equitable, and inclusive, reaching marginalized and hard-to-reach populations. Integrating fortification with maternal nutrition, early childhood development programs, and primary healthcare services can amplify its impact. Ultimately, ensuring adequate iron and zinc intake in under-5 children is not merely a nutritional intervention—it is a cornerstone of sustainable development and social equity [19].

7. Conclusion

Zinc and iron fortification is a scientifically proven, cost-effective strategy to combat hidden hunger in children under five, particularly in low- and middle-income countries where micronutrient deficiencies are widespread. These nutrients are essential for cognitive development, immune resilience, and physical growth during the critical preschool years. Fortifying commonly consumed foods—such as wheat flour, rice, and complementary foods—has been shown to reduce anemia, support brain function, and lower rates of stunting and infection. As countries strive to achieve the Sustainable Development Goals, especially those related to health, nutrition, and education, scaling up fortification programs must be prioritized. Long-term success depends on the integration of sound public policy, technological feasibility, quality control, and community awareness. Public-private partnerships and sustained funding are equally crucial to expand reach and ensure effectiveness. Investing in zinc and iron fortification is not just a health intervention—it is a foundational step toward building a healthier, more equitable future for all children.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] World Health Organization. (2020). Guideline: Use of Multiple Micronutrient Powders for Home Fortification of Foods Consumed by Infants and Children.
- [2] Black RE, Victora CG, et al. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*.
- [3] Dewey KG, et al. (2001). Effect of iron supplementation on growth and cognitive development. *J Nutr*.
- [4] Bhutta ZA, Ahmed T, et al. (2013). What works? Interventions for maternal and child undernutrition and survival. *The Lancet*.
- [5] UNICEF. (2024). State of the World's Children Report.

- [6] Mayo-Wilson E, et al. (2014). Zinc supplementation for preventing mortality and morbidity in children. *Cochrane Database*.
- [7] Allen LH. (2003). Interventions for micronutrient deficiency control in developing countries: past, present and future. *Journal of Nutrition*, 133 (11 Suppl 2), 3875S–3878S.
- [8] Lopez de Romaña D, et al. (2016). Efficacy and safety of iron-fortified foods for children under five years of age. *Cochrane Database of Systematic Reviews*, Issue 8.
- [9] Neufeld LM, et al. (2007). The impact of zinc supplementation on child health: a meta-analysis of randomized controlled trials. *Food and Nutrition Bulletin*, 28 (3_suppl3), S399–S414.
- [10] Anderson, G. J., and D. M. Frazer. 2017. Current understanding of iron homeostasis. *The American Journal of Clinical Nutrition* 106(6): 1559S-66S.
- [11] Zhang L, Kleiman-Weiner M, Luo R, et al. Multiple micronutrient supplementation reduces anemia and anxiety in rural China's elementary school children. *J Nutr* 2013; 143: 640-647.
- [12] Pasricha SR, Drakesmith H, Black J, et al. Control of iron deficiency anemia in low- and middle-income countries. *Blood* 2013; 121: 2607-2617.
- [13] Eden AN, Sandoval C. Iron deficiency in infants and toddlers in the United States. *Pediatr Hematol Oncol* 2012; 29: 704-709.
- [14] Radlowski EC, Johnson RW. Perinatal iron deficiency and neurocognitive development. *Front Hum Neurosci* 2013; 7: 585.
- [15] Abdullah K, Kendzerska T, Shah P, et al. Efficacy of oral iron therapy in improving the developmental outcome of preschool children with nonanaemic iron deficiency: a systematic review. *Public Health Nutr* 2013; 16: 1497- 1506.
- [16] Duley L, Batey N. Optimal timing of umbilical cord clamping for term and preterm babies. *Early Hum Dev* 2013; 89: 905-908.
- [17] Hurrell, R. F., Juillerat, M. A., Reddy, M. B., Lynch, S. R., Das-senko, S. A., and Cook, J. D. 1992. Soy protein, phytate, and iron absorption in man. *Am. J. Clin. Nutr.* 56: 573-578.
- [18] Imdad A, Bhutta ZA. (2011). Effect of preventive zinc supplementation on linear growth in children under 5 years of age in developing countries: a meta-analysis of studies for input to the Lives Saved Tool. *BMC Public Health*, 11 (Suppl 3), S22.
- [19] Erickson-Owens DA, Mercer JS, Oh W. Umbilical cord milking in term infants delivered by cesarean section: a randomized controlled trial. *J Perinatol* 2012; 32: 580-584.