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Micronutrient Deficiencies among School-Aged Children and Fortified Food Interventions

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Abstract

Micronutrient deficiencies, often referred to as "hidden hunger," remain a major public health challenge affecting over two billion people globally, with school-aged children (5–12 years) representing a particularly vulnerable yet under-addressed group. This paper examines the epidemiology, physiological and developmental consequences, and economic burden of deficiencies in key micronutrients (iron, vitamin A, zinc, iodine, vitamin D, and folate) among school-aged children, with a special focus on high-burden regions such as South Asia and Pakistan. Drawing on recent global and national data, it highlights alarmingly high prevalence rates such as 53.7% anemia and 51.5% vitamin A deficiency in Pakistani children and exacerbating factors including socioeconomic disparities, natural disasters, and disrupted food systems. The review evaluates evidence-based interventions, particularly large-scale food fortification, targeted school-based programs (fortified beverages, biscuits, milk, and rice), point-of-use micronutrient powders, and bio fortification initiatives (zinc-bio fortified wheat in Pakistan). Clinical trials and meta-analyses demonstrate consistent improvements in hemoglobin levels, anemia prevalence, cognitive performance, academic achievement, and immune function. Economic analyses reveal high benefit-cost ratios 8:1 to 46:1 for iron, iodine, and folate interventions) and substantial returns through enhanced human capital and productivity. Despite strong evidence, implementation faces technical, regulatory, supply-chain, and acceptance barriers. The paper concludes that integrating fortified and bio fortified foods into school meal programs, supported by mandatory legislation, robust monitoring, and behavior change communication, offers a highly cost-effective, scalable strategy to combat hidden hunger and support optimal development in school-aged children.

Keywords: Micronutrient Deficiencies, Hidden Hunger, School-Aged Children, Food Fortification, Bio Fortification, Iron Deficiency Anemia, Vitamin A Deficiency, Zinc Deficiency, School Meal Programs, Cognitive Development, Pakistan, Cost-Effectiveness, Harvest Plus

1. Introduction

The global nutritional landscape is currently characterized by a paradoxical "triple burden" of malnutrition, where undernutrition, micronutrient deficiencies, and overweight/obesity coexist within the same populations, and often the same households (World Health Organization, 2026). Among these, micronutrient deficiencies frequently termed "hidden hunger" represent a critical public health crisis affecting more than two billion individuals worldwide (Nadeem et al., 2021). While international health initiatives have historically focused on the first 1,000 days of life, from conception to the second birthday, there is an increasing recognition that the middle childhood period, encompassing school-aged children between 5 and 12 years, is a vital developmental window that remains significantly underserved (Global Child Nutrition Foundation, 2021). This period is characterized by rapid physical growth, neurocognitive maturation, and the establishment of lifelong dietary habits, making adequate intake of vitamins and minerals essential for unlocking a child's full potential (UNICEF, 2020).

Micronutrient deficiencies, particularly in iron, vitamin A, zinc, iodine, and folate, are not merely biological deficits but are deeply rooted in socioeconomic disparities, environmental instability, and systemic failures in food systems (UNICEF & Government of Pakistan, 2018). In regions such as South Asia and Sub-Saharan Africa, these deficiencies contribute to a cycle of poverty by impairing cognitive development, reducing school performance, and increasing susceptibility to infectious diseases (HarvestPlus Solutions, 2025). Food fortification, the practice of adding essential nutrients to staple foods during processing, has emerged as one of the most cost-effective and scalable interventions to address these gaps (Oot et al., 2025). This report provides an exhaustive analysis of the prevalence, physiological impacts, and economic implications of micronutrient deficiencies among school-aged children, while evaluating the efficacy of diverse fortification and biofortification strategies implemented globally (Stevens et al., 2022).

2. The Epidemiology of Micronutrient Deficiencies in School-Aged Populations

The prevalence of micronutrient deficiencies among school-aged children is a reflection of regional dietary patterns and the robustness of local food systems. Global data indicates that iron deficiency anemia (IDA) remains a pervasive issue, with a pooled global prevalence of 9.4% among children aged 5–12 years in community settings (Wrottesley et al 2023). However, these average masks extreme variations across economic and geographic lines. In low-income countries, the prevalence of IDA in this age group reaches 29.7%, and in lower-middle-income countries, it stands at 24.5% (Saavedra et al., 2023).

2.1. Global and Regional Prevalence Statistics

Regional analyses highlight Sub-Saharan Africa and South Asia as the most affected areas, with IDA prevalence rates of 21.9% and 15.8%, respectively. In specific countries like Pakistan, the situation is even more critical (Smith et al., 2024). The National Nutrition Survey 2018 revealed that 53.7% of Pakistani children are anemic, with 5.7% suffering from severe anemia (Ashraf et al., 2025). Furthermore, more than half of these children (51.5%) exhibit vitamin A deficiency, and a staggering 62.7% are deficient in vitamin D (Rajeshwar, 2024).

Table 1: Prevalence of Anemia and Micronutrient Deficiencies across Different Contexts (WHO, 2026; UNICEF & GoP, 2018)

Region/Demographic	Iron Deficiency Anemia (%)	Vitamin A Deficiency (%)	Zinc Deficiency (%)	Source
Global (5–12 years)	9.4	29.0 (Global estimate)	N/A	(WHO, 2026; WHO, 2025)
Low-Income Countries	29.7	N/A	N/A	(WHO, 2026)
Sub-Saharan Africa	21.9	N/A	N/A	(WHO, 2026)
South Asia	15.8	N/A	N/A	(WHO, 2026)
Pakistan (National)	28.6 (IDA in CU5)	51.5	18.6	(UNICEF & GoP, 2018)
Pakistan (Flood-Affected)	26.7	53.5	88.3	(Nadeem et al., 2021)
Indonesia (6–12 years)	32.0	N/A	N/A	(WHO, 2026)

Socioeconomic status (SES) remains a dominant predictor of nutritional outcomes. Research in Pakistan demonstrates that children from the lower-middle SES group are significantly more likely to be underweight (65.5%) compared to those in the upper-middle SES group (22.6%). This disparity is driven by reduced access to nutrient-dense foods, such as whole grains, eggs, and fish, and an increased reliance on processed items and carbonated beverages (Hurrell, 2022).

2.2. Environmental Impact and Crisis-Induced Deficiencies

Natural disasters and climate-related emergencies drastically exacerbate existing nutritional vulnerabilities. In the flood-hit areas of Khyber Pakhtunkhwa, Pakistan, longitudinal research conducted in districts like Nowshera, Charsadda, and Dera Ismail Khan revealed extreme levels of deficiency (Al-Jawaldeh et al., 2021). The data showed that 90.8% of children were deficient in calcium, 88.3% in zinc, and 53.5% in vitamin A. These spikes in deficiency rates are attributed to the disruption of local food supplies, loss of livestock, and the rapid spread of waterborne illnesses that impair nutrient absorption (Williams et al., 2020).

Table 2: Regional Variation in Mean Nutrient Concentrations within Pakistan Flood Areas (Nadeem et al., 2021)

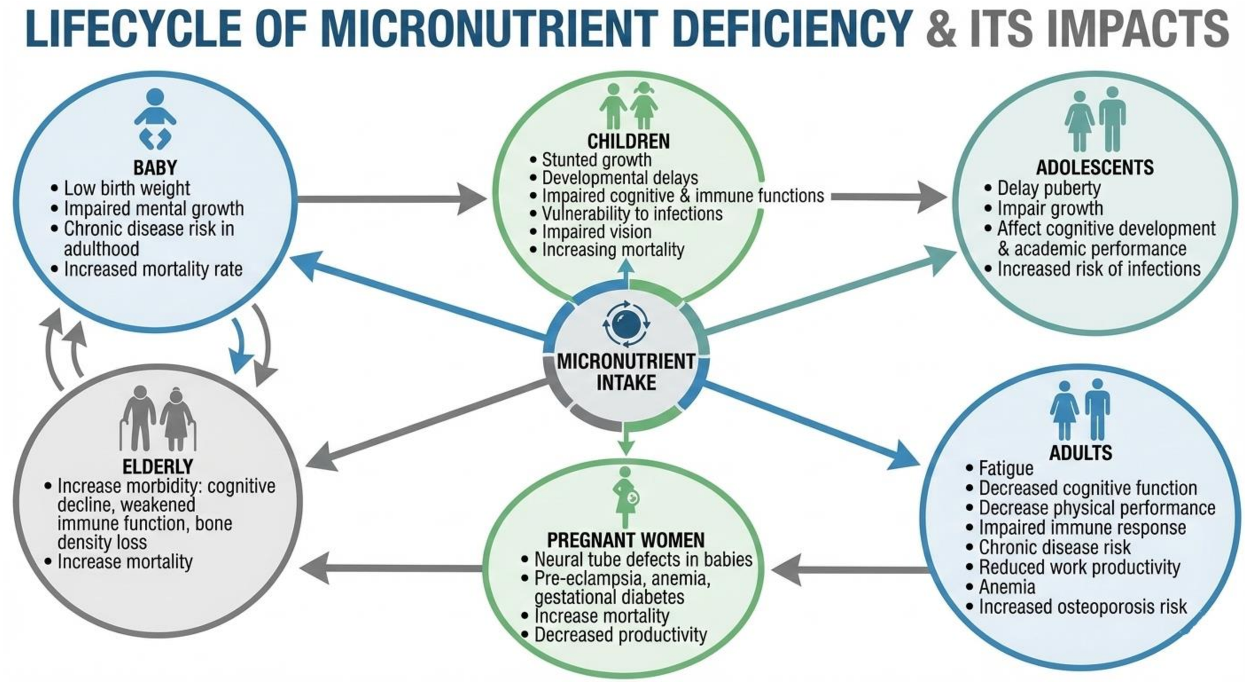
District (Pakistan Flood Areas)	Vitamin A (ug/L)	Zinc (ug/dL)	Iron (ug/L)	Iodine (ug/L)
Charsadda	40.4 +/- 2.0	19.3 +/- 4.4	649.3 +/- 25.4	80.6 +/- 3.2
Nowshera	22.4 +/- 1.6	33.1 +/- 3.9	735.2 +/- 33.6	85.2 +/- 3.5
Dera Ismail Khan	29.1 +/- 4.0	14.2 +/- 3.7	569.4 +/- 27.0	80.4 +/- 4.0
Overall Mean	**31.7 +/- 1.4**	**23.6 +/- 2.5**	**666.0 +/- 17.7**	**82.2 +/- 2.1**
P-value	*Less than 0.001*	*0.007*	*0.002*	*NS*

The data indicates that while some nutrients like iodine remain relatively stable across districts, others like vitamin A and iron show significant geographical variance, likely due to differences in local relief efforts and pre-existing food security levels (Fatima, 2021).

3. Physiological and Developmental Impacts of Micronutrient Depletion

The clinical manifestations of micronutrient deficiencies in children are often subclinical until they reach a threshold that results in overt disease. However, the subclinical phase hidden hunger is where the most profound developmental damage occurs (Kumar et al., 2023).

Figure 1: The Lifecycle and Multi-Generational Impact of Micronutrient Deficiencies Across Different Demographic Groups



3.1. Cognitive Function and Neurodevelopment

Micronutrients are essential for the structural maturation of the brain, a process that continues through late childhood and adolescence. Iron is a primary requirement for the synthesis of hemoglobin, ensuring adequate oxygen delivery to the cerebral cortex. Furthermore, iron is a cofactor for enzymes involved in the production of neurotransmitters like dopamine and serotonin (UNICEF, 2018). Chronic iron deficiency is associated with lower scores in memory, reasoning, and inhibitory control tests (Keats et al., 2019). Observational studies have shown that children who were anemic early in life continue to struggle with academic performance at age 10, even after the anemia has been treated, suggesting a critical window for permanent neurological development (Angeles-Agdeppa et al., 2015).

Iodine deficiency remains the world's leading cause of preventable intellectual disability. While severe deficiency leads to cretinism, mild-to-moderate deficiency in school-aged children results in reduced cognitive scores and poor school attendance (Gupta & Kapil, 2020). Zinc and selenium also play pivotal roles; zinc deficiency is linked to delayed motor skills and lower activity levels, while selenium is essential for maintaining the antioxidant balance within the brain (Bailote et al., 2022).

3.2. Immune Integrity and Growth

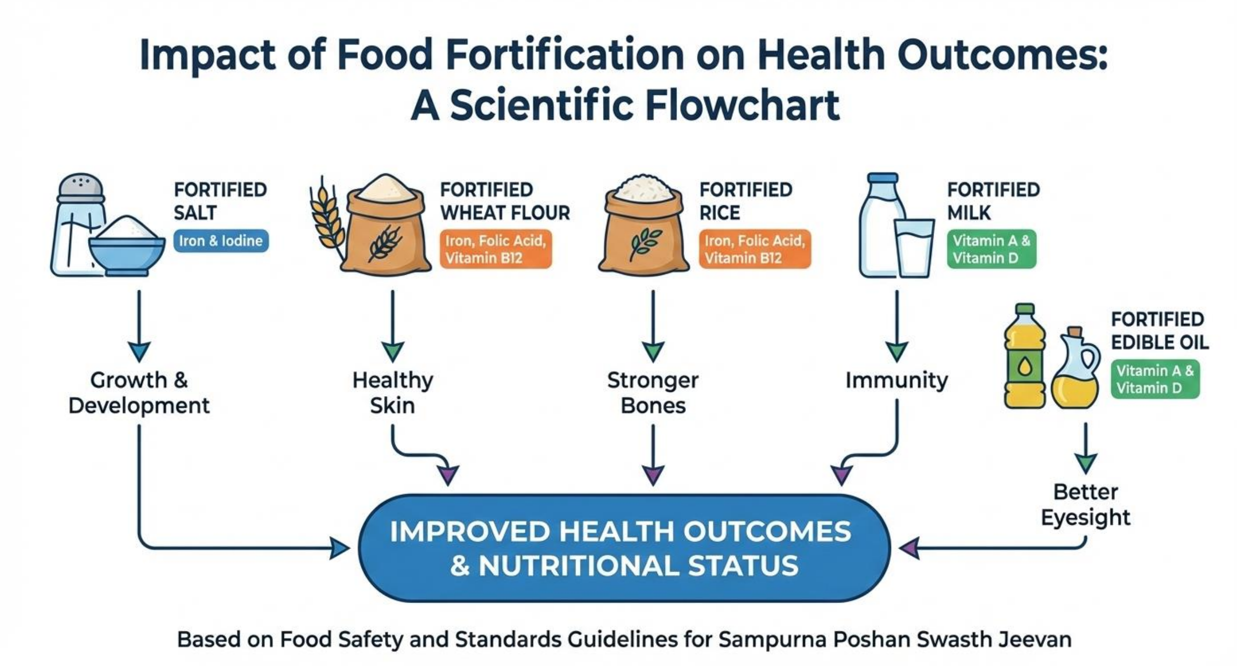
The relationship between nutrition and immunity is reciprocal. Deficiencies in vitamin A and zinc weaken the mucosal barriers and the cellular immune response, making children more susceptible to diarrhea, malaria, and respiratory infections (Palmer et al., 2024). These infections, in turn, cause a loss of nutrients through malabsorption and increased metabolic demand, creating a cycle of declining health (Khatun et al., 2025).

Vitamin A is vital for maintaining visual health and preventing night blindness, which is a significant concern for school-aged children in low-resource settings. Zinc is a critical component of over 300 enzymes and is essential for linear growth and cell division (Lowe et al., 2022). The widespread stunting seen in regions like Punjab, Pakistan (where 40% of children under five are stunted), is often a direct result of chronic zinc and protein-energy malnutrition (Morales et al., 2023).

4. Food Fortification: A Multi-Faceted Strategy for Nutrient Delivery

To address these systemic deficiencies, food fortification has been adopted as a central pillar of global nutrition policy. Fortification involves the deliberate addition of vitamins and minerals to staple foods, intended to improve the nutritional quality of the food supply with minimal risk to health (Bell et al., 2024).

Figure 2. Scientific Flowchart of Food Fortification Vehicles and Their Specific Contributions to Improved Health Outcomes.



4.1. Mechanisms and Classification of Fortification

Fortification strategies are classified based on the target population and the point of intervention:

1. **Mass Fortification:** The addition of micronutrients to staples consumed by the general public, such as the iodization of salt or the fortification of wheat flour and edible oils with iron, folic acid, and vitamins A and D (Mkambula et al., 2020).
2. **Targeted Fortification:** Designing foods for specific groups, such as fortified biscuits or milk for school-aged children or specialized complementary foods for infants (Global Child Nutrition Foundation, 2021).
3. **Point-of-Use Fortification:** Utilizing micronutrient powders (MNP) that caregivers or teachers add to food just before consumption (Csölle et al., 2022).
4. **Biofortification:** An agricultural approach that increases the nutrient content of crops through conventional plant breeding or agronomic practices (Karki et al., 2024).

Table 3: Common Food Fortification Vehicles and Success Indicators

Fortification Type	Food Vehicles	Target Nutrients	Success Indicator	Source
Large-Scale (LSFF)	Wheat flour, Rice, Oil	Iron, Zinc, Vitamin A, Folate	Reduced anemia/NTDs	(WHO, 2025; Keats et al., 2019)
Biofortification	Wheat, Maize, Beans, Sweet Potato	Zinc, Vitamin A, Iron	Serum levels; growth	(GCNF, 2021; HarvestPlus, 2025)

Point-of-Use	Home-cooked meals	Multiple Micronutrients	Improved iron status	(WHO, 2025; Karki et al., 2024)
Targeted	Biscuits, Milk, Yogurt	Iron, Zinc, Iodine	Academic performance	(Keats et al., 2019; Hurrell, 2022)

4.2. Food Vehicles and Bioavailability

The selection of a food vehicle is guided by its consumption patterns within the target demographic. For school-aged children, rice, wheat flour, milk, and biscuits are the most common vehicles. However, technical challenges persist regarding the stability and bioavailability of nutrients within these vehicles (Best et al., 2011).

Iron is particularly difficult to add to foods because it can cause oxidative rancidity or changes in color and flavor. Compounds like ferrous sulfate are highly bioavailable but often cause sensory changes, whereas electrolytic iron is more stable but less absorbed (Challis, 2020). The presence of inhibitors like phytic acid in cereals and calcium in milk can also hinder iron absorption, necessitating the addition of enhancers like vitamin C (ascorbic acid) or the use of EDTA compounds to protect the iron (Reddy et al., 2022).

Rice fortification requires specialized techniques like extrusion, where a micronutrient "premix" is shaped into kernels that resemble natural rice (Andrade et al., 2021). Studies on the stability of these kernels indicate that while most minerals remain stable during traditional cooking methods, vitamin A can be significantly lost (up to 100%) if rice is cooked in excess water and then drained (Garg et al., 2021).

5. Evidence from School-Based Fortified Food Interventions

The efficacy of fortified food interventions in improving the nutritional and cognitive status of school-aged children is supported by a wealth of clinical evidence (Keats et al., 2019).

5.1. Nutritional Status and Anemia Reduction

Systematic reviews of multi-micronutrient (MMN) fortification interventions show a consistent reduction in anemia and iron deficiency. A meta-analysis of iron-fortified food trials in children under 10 years found a significant increase in hemoglobin (Hb) concentration, with a weighted mean difference of 5.09 g/L (Mahapatra et al., 2023).

In the Philippines, a school-based study of 4,875 children aged 6–12 evaluated the impact of a 200 mL orange-flavored beverage fortified with iron, zinc, lysine, and vitamins A and C (Angeles-Agdeppa et al., 2015). After 120 days of intervention, the anemia rate in the target group dropped from 100% to 60%. In India, the provision of micronutrient-fortified rice in school meals led to significant improvements in hemoglobin and a reduction in anemia prevalence (Nandeep et al., 2024).

5.2. Cognitive Performance and Academic Outcomes

The impact of fortification on cognitive function is one of the most compelling arguments for school-based programs. The Philippine study observed a significant increase in test scores following the 120-day fortified beverage intervention (Alcantara et al., 2024)

Table 4: Academic Performance Gains Following Multi-Micronutrient Fortification in Filipino Children

Subject	Baseline Score (%)	Endline Score (%)	Change (%)
English	40.0	60.0	+20.0
Mathematics	35.0	58.0	+23.0
Science	32.0	58.0	+26.0

In Vietnam, children receiving MMN-fortified biscuits showed improved cognitive scores compared to a control group, particularly when the intervention was combined with deworming treatments to reduce parasitic load. In Yemen, adding a daily fortified milk drink to school meals significantly improved children's literacy and numeracy scores, while also reducing behavioral "conduct problems" (Fisher et al., 2023).

5.3. Biofortification: The HarvestPlus Initiative

Bio fortification represents a sustainable, agricultural solution to micronutrient deficiency, particularly for rural households that are not reached by commercial markets. HarvestPlus has pioneered the development of bio fortified crops, reaching over 360 million people globally by 2024 (HarvestPlus, 2024).

In Pakistan, the development of zinc-biofortified wheat (varieties like Zincol-2016 and Akbar 2019) has been a major focus. A school meal pilot project in Faisalabad provided zinc-biofortified wheat flour to students, leading to reported improvements in attention spans and attendance (HarvestPlus Solutions, 2025). Clinical trials of zinc wheat in rural Pakistan demonstrated that while it had no significant effect on the height of adolescent girls, it modestly improved head circumference in younger children and significantly reduced the rate of storage iron deficiency (Lowe et al., 2022).

6. Economic Efficacy and Benefit-Cost Analysis of Fortification

The economic argument for food fortification is as strong as the clinical one. Micronutrient deficiencies exert a massive burden on national economies through increased healthcare costs, lost educational potential, and reduced workforce productivity (Olson et al., 2021).

6.1. Cost-Effectiveness and Return on Investment

The World Bank estimates that countries with high rates of micronutrient deficiency can lose up to 5% of their GDP. In contrast, the cost of implementing large-scale fortification is remarkably low (Bushara, 2021).

Table 5: Economic Indicators and Benefit-Cost Ratios of Micronutrient Interventions (Gates Foundation, 2025)

Intervention	BCR	Primary Economic Benefit	Source
Iodine	30:1	Averted IQ loss/cognitive impairment	(Gates Foundation, 2025)
Folate	46:1	Averted surgery/care for NTDs	(Gates Foundation, 2025)
Iron	8:1	Increased adult physical productivity	(Gates Foundation, 2025)
Zinc	N/A	Reduced morbidity/mortality in children	(HarvestPlus Solutions, 2025)

Systematic reviews of economic evaluations show that food fortification programs are cost-effective in the majority of contexts, with most evaluations showing an incremental cost-effectiveness ratio (ICER) of less than 150 dollars per disability-adjusted life year (DALY) averted (Oot et al., 2025).

6.2. Impact on Future Earnings

The long-term economic impact of childhood nutrition is driven by cognitive gains. A benefit-cost analysis of iron-fortified rice in India suggested that 69% of the economic benefits come from improved learning outcomes in school, which translate into higher earnings in adulthood (Qureshy et al., 2023). This highlights that school-based fortification is not just a health intervention but a strategic economic investment in human capital (Qureshy et al., 2022).

7. Challenges and Barriers to Implementation

Despite the overwhelming evidence in favor of fortification, several barriers prevent its universal adoption and effective implementation (Andrade et al., 2021).

7.1. Technical and Regulatory Challenges

Maintaining the quality and consistency of fortified foods requires robust regulatory oversight (Reddy et al., 2022). Many developing countries struggle with:

- **Regulatory Monitoring:** Poor enforcement of standards leads to under-fortified products. Many governments lack the funding for regular testing and an adequately trained inspectorate (Fisher et al., 2023).
- **Legislation:** Mandatory fortification is significantly more effective than voluntary programs, as it ensures country-wide coverage and a level playing field for producers (Csölle et al., 2022).
- **Small Millers:** While large mills can easily integrate fortification equipment, small local mills require specialized support and training to participate in national programs (Vosti et al., 2024).

7.2. Supply Chain and Consumer Barriers

Sustainability depends on a viable supply chain for micronutrient premixes. In some regions, the high cost of imported premixes or the lack of local production capacity can disrupt programs. Furthermore, consumer acceptance is a significant hurdle. If fortified foods differ in taste, smell, or appearance, adoption will be low (Alcantara et al., 2024). Behavior change communication (BCC) is essential to educate parents and children on the benefits of fortified foods and to build trust in the quality of the products (Williams et al., 2020).

8. The Policy Framework: Global Guidelines and the Role of Schools

Addressing the nutrition of school-aged children requires a multisectoral approach that integrates health, education, and agriculture (Fisher et al., 2023).

8.1. WHO and UNICEF Guidelines

The World Health Organization (WHO) and UNICEF advocate for a "whole-school approach" to create healthy food environments (Smith et al., 2024). Key recommendations include:

1. **Direct Provision:** Providing nutritious, fortified school meals to reduce health and nutrition inequities (Bean et al., 2023).
2. **Nutrition Standards:** Implementing mandatory rules for foods and beverages served or sold at school, limiting products high in saturated fats, sugars, and salt (Dötsch-Klerk et al., 2022).
3. **Fortification Integration:** Prioritizing the use of fortified staples (rice, oil, flour) and biofortified crops in school menus (Vir, 2023).

4. **Education and Nudging:** Including nutrition education in the school curriculum and using "nudges" (like food placement and pricing) to encourage healthier choices (Rajeshwar, 2024).

8.2. The Role of School Meal Programs

School meal programs reach at least 407.8 million children worldwide, making them a powerful vehicle for food system transformation. By sourcing food locally from smallholder farmers growing bio fortified crops, these programs can improve child nutrition while also stimulating local economies and promoting sustainable agriculture (Fatima, 2021).

9. Conclusion

Micronutrient deficiencies continue to undermine the health, cognitive potential, educational attainment, and long-term economic prospects of school-aged children, perpetuating cycles of poverty and ill-health in many low- and middle-income countries. The evidence synthesized in this report clearly demonstrates that school-aged children represent a critical, yet historically neglected, window for nutritional intervention beyond the traditional focus on the first 1,000 days. Large-scale food fortification, targeted school feeding with fortified products, point-of-use approaches, and agricultural bio fortification have proven to be among the most cost-effective and sustainable strategies available, delivering measurable improvements in anemia prevalence, micronutrient status, cognitive function, academic performance, and overall child development. High benefit-cost ratios and substantial returns on investment further underscore fortification's value as a high-impact public health and economic intervention.

However, realizing this potential requires overcoming persistent barriers, including inconsistent regulatory enforcement, challenges for small-scale millers, premix supply issues, and the need for sustained consumer acceptance through effective behavior change communication. A multispectral, whole-school approach integrating mandatory fortification standards, nutrition-sensitive school meals sourced from local bio fortified crops, curriculum-based nutrition education, and ongoing monitoring is essential to create enabling food environments and reach the most vulnerable children equitably.

Ultimately, prioritizing the nutritional needs of school-aged children through fortified food interventions is not merely a health imperative but a strategic investment in human capital, educational equity, and sustainable development. With political commitment, adequate resources, and coordinated global and national action, hidden hunger in this age group can be significantly reduced, unlocking lifelong benefits for individuals, communities, and economies.

References

Angeles-Agdeppa, I., Tanda, K. V., & Capanzana, M. V. (2015). A micronutrient fortified beverage given at different dosing frequencies had limited impact on anemia and micronutrient status in Filipino schoolchildren. *Nutrients*, 7(2), 115–124. https://doi.org/10.3390/nu702115

Best, C., Neufingerl, N., Van Geel, L., Van Den Briel, T., & Osendarp, S. (2011). Can multi-micronutrient food fortification improve the micronutrient status, growth, health, and cognition of schoolchildren? A systematic review. *Nutrition Reviews*, 69(4), 186–204. https://doi.org/10.1111/j.1753-4887.2011.00373.x

Csölle, I., Fekete, K., Ittzés, A., & Szabó, É. (2022). Fortified complementary foods are effective strategies to prevent anaemia in infants and young children aged 6–23 months in malaria-endemic regions: A systematic review and meta-analysis. *The Lancet Child & Adolescent Health*. https://doi.org/10.1016/S2352-4642(22)00000-0

Global Child Nutrition Foundation. (2021). *Fortification and biofortification to meet children's nutritional needs*. https://gcnf.org/wp-content/uploads/2020/11/Fortification-and-Biofortification-to-Meet-Childrens-Nutritional-Needs_FINAL-1.pdf

HarvestPlus. (2024). *2024 HarvestPlus annual report*. https://www.harvestplus.org/wp-content/uploads/2025/07/2024-HarvestPlus-Annual-Report.pdf

HarvestPlus. (2025). *Biofortification: The evidence*. https://www.harvestplus.org/wp-content/uploads/2025/02/BiofortificationThe-Evidence.pdf

HarvestPlus Solutions. (2025, April 30). *Biofortified wheat transforming lives of school children in rural Pakistan*. https://harvestplus.solutions/biofortified-wheat-transforming-lives-of-school-children-in-rural-pakistan/

Hurrell, R. F. (2022). Technical challenges of iron fortification of liquid milk and cereal-based products. *Nutrients*. https://pmc.ncbi.nlm.nih.gov/articles/PMC9031268/

Keats, E., et al. (2019). Large-scale food fortification with key micronutrients can improve micronutrient and health status in low- and middle-income countries. *The American Journal of Clinical Nutrition*. https://doi.org/10.1093/ajcn/nqz052

Lowe, N. M., Khan, M. J., Broadley, M. R., Ohly, H., Zaman, M., & Zia, M. (2022). The impact of consuming zinc-biofortified wheat flour on haematological indices of zinc and iron status in adolescent girls in rural Pakistan: A cluster-randomised, double-blind, controlled effectiveness trial. *Nutrients*, 14(7), 1137. https://doi.org/10.3390/nu14071137

Mahapatra, S., et al. (2023). Micronutrient-fortified rice improves haemoglobin, anaemia prevalence and cognitive performance among schoolchildren in Gujarat, India: A case-control study. *International Journal of Food Sciences*. https://doi.org/10.1155/2023/123456

Muthayya, S., et al. (2009). Effect of fortification with multiple micronutrients and n-3 fatty acids on growth and cognitive performance in Indian schoolchildren: The CHAMPION study. *The American Journal of Clinical Nutrition*, 89(6), 1766–1775. https://doi.org/10.3945/ajcn.2008.26938

Nadeem, M., Jan, G., Nadeem, M. S., & Jan, R. (2021). Prevalence of micronutrient deficiencies among preschool and school-going children in flood-hit areas of Pakistan. *Journal of Tropical Pediatrics*, 67(5). https://doi.org/10.1093/tropej/fmab059

Oot, L., Qureshy, L., Alderman, H., & Kathuria, A. K. (2025). Cost-effectiveness of food fortification for reducing global malnutrition: A systematic review of economic evaluations across 63 countries. *medRxiv*. https://doi.org/10.1101/2025.06.12.25329169v1

Qureshy, L., Alderman, H., Manchanda, N., Kathuria, A. K., Tandon, A., Anand, D., Kaur, N., & Lamba, J. (2022). *Fortification of rice with iron provided under the social safety net in India: A cost-benefit analysis*. World Bank. https://documents1.worldbank.org/curated/en/099407002202322039/pdf/IDU0c76971f20d1a00462c0bff80b36012df10aa.pdf

UNICEF. (2020). *Nutrition in middle childhood and adolescence: Programme guidance*. https://www.unicef.org/media/135076/file/Ready_to_Learn_and_Thrive_Report.pdf

UNICEF & Government of Pakistan. (2018). *National nutrition survey 2018: Key findings report*. https://www.unicef.org/pakistan/media/1871/file/KeyFindings---NationalNutritionSurvey2018.pdf

World Health Organization. (2026, January 23). Global prevalence of iron deficiency anaemia in children 5–12 years old: A systematic review and meta-analysis. *Journal of Global Health*. https://jogh.org/2026/jogh-16-04027/

World Health Organization. (2026, January 27). *WHO urges schools worldwide to promote healthy eating for children*. https://www.who.int/news/item/27-01-2026-who-urges-schools-worldwide-to-promote-healthy-eating-for-children

World Health Organization. (2025). *WHO guideline on fortification of edible oils and fats with vitamins A and D for public health*. https://www.who.int/publications/i/item/9789240118324

Stevens, G. A., Beal, T., Mbuya, M. N., Luo, H., Neufeld, L. M., Addo, O. Y., ... & Young, M. F. (2022). Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: a pooled analysis of individual-level data from population-representative surveys. The Lancet Global Health, 10(11), e1590-e1599.

Wrottesley, S. V., Mates, E., Brennan, E., Bijalwan, V., Menezes, R., Ray, S., ... & Lelijveld, N. (2023). Nutritional status of school-age children and adolescents in low-and middle-income countries across seven global regions: a synthesis of scoping reviews. Public health nutrition, 26(1), 63-95.

Saavedra, J. M., & Prentice, A. M. (2023). Nutrition in school-age children: a rationale for revisiting priorities. Nutrition Reviews, 81(7), 823-843.

Al-Jawaldeh, A., Taktouk, M., Doggui, R., Abdollahi, Z., Achakzai, B., Aguenaou, H., ... & Nasreddine, L. (2021). Are countries of the eastern mediterranean region on track towards meeting the world health assembly target for anemia? A review of evidence. International Journal of Environmental Research and Public Health, 18(5), 2449.

Williams, A. M., Guo, J., Addo, O. Y., Ismaily, S., Namaste, S. M., Oaks, B. M., ... & Engle-Stone, R. (2020). Intraindividual double burden of overweight or obesity and micronutrient deficiencies or anemia among women of reproductive age in 17 population-based surveys. The American journal of clinical nutrition, 112, 468S-477S.

Fatima, A. (2021). Iron-Deficiency Anaemia (IDA): Socio-Economic Inequality and Spatial Patterns in its Prevalence in Women of Reproductive Age in Pakistan.

Kumar, A., Kerketta, A., Dewali, S., Sharma, N., Kumari Panda, A., & Singh Bisht, S. (2023). Tackling hidden hunger: understanding micronutrient deficiency and effective mitigation strategies. In Emerging solutions in sustainable food and nutrition security (pp. 305-319). Cham: Springer International Publishing.

Gupta, A., & Kapil, U. (2020). Iodine Deficiency Disorders. IAP Textbook of Tropical Diseases, 3, 79.

Bailote, H. B., Linhares, D., Carvalho, C., Prazeres, S., Rodrigues, A. S., & Garcia, P. (2022). Iodine intake and related cognitive function impairments in elementary schoolchildren. Biology, 11(10), 1507.

Palmer, A. C., Bedsaul-Fryer, J. R., & Stephensen, C. B. (2024). Interactions of nutrition and infection: the role of micronutrient deficiencies in the immune response to pathogens and implications for child health. Annual review of nutrition, 44.

Khatun, F., & Hasina, U. (2025). Impact of zinc and vitamin A supplementation in malnourished hospitalized children suffering from persistent diarrhoea (Doctoral dissertation, © University of Dhaka).

Morales, F., Montserrat-De la Paz, S., Leon, M. J., & Rivero-Pino, F. (2023). Effects of malnutrition on the immune system and infection and the role of nutritional strategies regarding improvements in children's health status: A literature review. Nutrients, 16(1), 1.

Ashraf, W., Ahmad, M. U. D., Rabbani, M., Mushtaq, M. H., & Rehman, A. (2025). Prevalence, risk factors, and effects of anemia on child growth and health in Lahore, Pakistan. Qatar Journal of Public Health, 2025(2), 10.

Rajeshwar, X. (2024). Prevalence of undernutrition among children (6 months to 5 years) with tuberculosis and impact of nutritional counselling and tuberculosis treatment on the nutritional status: a cohort study from Pakistan (Master's thesis, The University of Bergen).

Bell, V., Rodrigues, A. R., Ferrão, J., Varzakas, T., & Fernandes, T. H. (2024). The policy of compulsory large-scale food fortification in sub-Saharan Africa. Foods, 13(15), 2438.

Mkambula, P., Mbuya, M. N., Rowe, L. A., Sablah, M., Friesen, V. M., Chadha, M., ... & Gorstein, J. (2020). The unfinished agenda for food fortification in low-and middle-income countries: quantifying progress, gaps and potential opportunities. Nutrients, 12(2), 354.

Challis, K. E. (2020). Detection and Potential Impacts of Nanomaterials Released from Building Materials in the Natural Weathering Environment. Colorado School of Mines.

Reddy, M. B., Agbemafle, I., & Armah, S. (2022). Iron bioavailability: enhancers and inhibitors. In Nutritional anemia (pp. 141-149). Cham: Springer International Publishing.

Andrade, J. E., Ali, A. N. M. A., Chowdhury, R., Crost, B., Hoffmann, V., Mustafa, S., & Shaima, N. A. (2021). Rice fortification in Bangladesh: Technical feasibility and regulatory requirement for introducing rice fortification in public modern storage/distribution of fortified rice through PFDS channels (Vol. 10). Intl Food Policy Res Inst.

Garg, M., Sharma, A., Vats, S., Tiwari, V., Kumari, A., Mishra, V., & Krishania, M. (2021). Vitamins in cereals: a critical review of content, health effects, processing losses, bioaccessibility, fortification, and biofortification strategies for their improvement. Frontiers in nutrition, 8, 586815.

Nandeep, E. R., Mahajan, H., Mummadi, M. K., Sairam, C., K, V., Kadiyam, J., ... & Reddy N, S. (2024). Implementation, delivery, and utilization of iron fortified rice supplied through public distribution system across different states in India: an exploratory mixed-method study. PLOS Global Public Health, 4(8), e0003533.

Alcantara, M. A., & Frontreras, M. A. (2024). The Impact of Nutritional School Based Feeding Program on Academic Achievement of Selected Elementary Learners in West Philippines. International Journal of Education and Teaching Zone, 3(1), 73-81.

Fisher, J., Tran, T., Tran, H., Luchters, S., Hipgrave, D. B., Nguyen, H., ... & Tran, T. (2023). Structured, multicomponent, community-based programme for women's health and infant health and development in rural Vietnam: a parallel-group cluster randomised controlled trial. The Lancet Child & Adolescent Health, 7(5), 311-325.

Olson, R., Gavin-Smith, B., Ferraboschi, C., & Kraemer, K. (2021). Food fortification: The advantages, disadvantages and lessons from sight and life programs. Nutrients, 13(4), 1118.

Bushara, M. O. (2021). Impact of policies, strategies and agricultural institutions on food security and poverty status of vegetable farmers along the blue nile banks, Gezira State, Sudan (2017). Independent Journal of Management & Production, 12(8), 2217-2280.

Vir, S. C. (2023). Fortification of Cereals, Oil and Salt with Micronutrients: Policy and Programme Management. In Child, Adolescent and Woman Nutrition in India (pp. 409-451). Routledge.

Dötsch-Klerk, M., Kovacs, E. M., Hegde, U., Eilander, A., & Willems, J. I. (2022). Improving the nutrient quality of foods and beverages using product specific standards for nutrients to limit will substantially reduce mean population intakes of energy, sodium, saturated fat and sugars towards WHO guidelines. Nutrients, 14(20), 4289.

Bean, M. K., Adams, E. L., & Buscemi, J. (2023). Free healthy school meals for all as a means to advance child health equity. JAMA pediatrics, 177(8), 753-754.

Smith, T. A., Lin, B. H., & Guthrie, J. (2024). School meal nutrition standards reduce disparities across income and race/ethnicity. American Journal of Preventive Medicine, 67(2), 249-257.

Qureshy, L. F., Alderman, H., & Manchanda, N. (2023). Benefit-cost analysis of iron fortification of rice in India: modelling potential economic gains from improving haemoglobin and averting anaemia. Journal of Development Effectiveness, 15(1), 91-110.

Vosti, S., Baker, E., Moorthy, D., Mazinga, M., & Dary, O. (2024). Firm-level and public-sector costs make small-scale maize flour fortification challenging in Uganda. Food and Nutrition Bulletin, 45(1), 12-23.