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FOOD SYSTEM DETERMINANTS INFLUENCING THE SUCCESS OF IRON FORTIFICATION PROGRAMS AMONG CHILDREN IN SOUTHEAST ASIA: A SYSTEMATIC REVIEW

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Abstract

Background: Iron deficiency and anemia remain major public health challenges among children in Southeast Asia, contributing to impaired growth, cognitive development, and long-term health outcomes. Although iron fortification has been widely implemented, program effectiveness has remained inconsistent across the region. This systematic review aimed to examine food system determinants influencing the success of iron fortification programs among children in Southeast Asia and their implications for Indonesia. **Methods**: A systematic review was conducted following the PRISMA 2020 guidelines. Literature searches were performed using PubMed/MEDLINE and Scopus. Studies published between 2015 and 2026 were screened for eligibility. Quantitative, qualitative, mixed-methods, and implementation studies evaluating iron fortification interventions among children in Southeast Asia were included. Data were synthesized narratively using a food systems perspective. **Results:** Nine studies were included, primarily randomized controlled trials and community-based interventions conducted in Cambodia and Indonesia. Iron fortification interventions, particularly fortified rice delivered through school feeding programs, generally improved hemoglobin levels, micronutrient status, and cognitive outcomes. However, intervention effectiveness was influenced by adherence, cultural acceptability, caregiver practices, inflammation, gut health, and implementation sustainability. **Conclusions:** The success of iron fortification programs was influenced not only by nutrient delivery but also by broader food system determinants. Integrated food systems approaches were considered essential to improve child nutrition outcomes in Southeast Asia, particularly in Indonesia.

Keywords: Iron fortification, food systems, anemia, children, Southeast Asia.

Introduction

Iron deficiency and anemia remain among the most persistent public health and nutrition challenges affecting children globally, particularly in low- and middle-income countries.[1] The World Health Organization (WHO) estimated that anemia affected approximately 39.8% of children aged 6–59 months globally, equivalent to more than 269 million children, with Southeast Asia carrying one of the highest regional burdens.[2] Childhood anemia prevalence in Southeast Asia frequently exceeded 40%, particularly in countries such as Cambodia, Indonesia, and the Philippines, thereby remaining a moderate-to-severe public health problem.[3–6] According to the Indonesian Basic Health Research, anemia affected approximately 38.5% of children under five years, while iron deficiency remained highly prevalent among school-aged children and adolescents in Indonesia.[7] Persistent iron deficiency during childhood has been associated with impaired hemoglobin synthesis, reduced oxygen transport, weakened immunity, delayed physical growth, and poor cognitive development.[8–11]

Iron deficiency during infancy and childhood is particularly critical because rapid growth during these periods substantially increases physiological iron requirements.[12] Insufficient iron intake compromises hemoglobin synthesis and oxygen transport, resulting in iron deficiency anemia (IDA), impaired neurodevelopment, reduced attention span, weakened immunity, and delayed physical growth.[8–10] Beyond hematological consequences, chronic iron deficiency has been associated with irreversible cognitive deficits and poorer educational achievement later in life.[13–15] Mechanistically, inadequate iron availability disrupts erythropoiesis, mitochondrial energy metabolism, neurotransmitter synthesis, and immune cell function, thereby affecting both physical and cognitive development.[10,16]

In Southeast Asia, the persistence of childhood iron deficiency is closely linked to broader structural and food-system-related challenges.[17,18] Diets in many countries within the region remain heavily dependent on plant-based staple foods with low iron bioavailability and high phytate content, limiting iron absorption among children.[19,20] At the same time, socioeconomic inequalities, food insecurity, poor dietary diversity, infectious diseases, weak regulatory systems, fragmented supply chains, and uneven program coverage further exacerbate the burden of micronutrient deficiencies.[21,22] Evidence from multicounty analyses in South and Southeast Asia demonstrates that poverty, low maternal education, limited dietary diversity, and inadequate access to health services are strongly associated with childhood anemia.[5,23] Childhood anemia is not solely a biomedical problem, but also a consequence of interconnected food system determinants involving food production, processing, distribution, affordability, governance, and consumer behavior.[24,25]

Food fortification, particularly iron fortification of staple foods, has been widely promoted as a cost-effective and population-based strategy to reduce iron deficiency and improve child nutrition outcomes.[26,27] Common fortification vehicles in Southeast Asia include rice, wheat flour, fish sauce, soy sauce, and complementary foods.[28,29] Iron fortification programs have shown potential benefits in improving hemoglobin concentrations and reducing anemia prevalence among children. A recent systematic review reported that fortification and other food-based interventions generally improved hemoglobin status and reduced anemia prevalence in vulnerable populations.[30] However, despite decades of implementation, the effectiveness of iron fortification programs across Southeast Asia remains inconsistent.[27]

Several countries in the region continue to face substantial implementation barriers that limit the impact and sustainability of fortification programs. These barriers include weak monitoring and enforcement systems, affordability issues, limited dietary reach among rural populations, and variability in iron compound bioavailability.[31] Similar challenges have been highlighted by Indonesian experts, who emphasized the need for stronger surveillance systems, improved program monitoring, multisectoral collaboration, and evidence-based policy implementation to enhance the effectiveness of iron deficiency anemia prevention programs.[32] Fortification initiatives frequently struggle due to inadequate regulatory enforcement and inconsistent program implementation.[33] Furthermore, sociocultural acceptability, taste preferences, market accessibility, and household purchasing behaviors may influence the uptake and effectiveness of fortified foods among children.[34,35]

The significance of adopting a food systems perspective to comprehend the reasons why certain fortification programs are successful while others are unsuccessful is becoming more pronounced in recent literature. A food systems approach recognizes that nutritional outcomes are shaped not only by nutrient delivery itself, but also by interactions among agricultural systems, food industries, governance structures, market environments, health systems, and consumer practices.[36] Within this framework, the success of iron fortification programs depends on multiple interconnected determinants, including political commitment, multisectoral coordination, private-sector participation, regulatory capacity, food distribution infrastructure, affordability, and public trust.[37,38]

Given these gaps, a systematic synthesis focusing on food system determinants is needed to better understand the factors influencing the implementation and success of iron fortification programs among children in Southeast Asia. These determinants may be identified to enhance the sustainability of programs, strengthen future nutrition policies, and support fortification strategies that are more contextually appropriate in Indonesia and other Southeast Asian countries. Therefore, this systematic review aims to examine the food system determinants influencing the success of iron fortification programs targeting children in Southeast Asia and to explore the implications of these findings for strengthening fortification strategies in Indonesia.

Method

This systematic review was conducted to identify and synthesize evidence regarding food system determinants influencing the success of iron fortification programs among children in Southeast Asia. The review was prepared in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, and the study selection process will be presented using a PRISMA flow diagram (**Figure 1)**. The review protocol was prospectively registered in PROSPERO.

A systematic literature search was conducted on 15 May 2026 using two electronic databases, namely PubMed/MEDLINE and Scopus. The search strategy combined keywords related to iron fortification, child populations, food system determinants, implementation factors, and Southeast Asia. Terms such as "iron fortification," "food fortification," "fortified rice," "children," "implementation," "barriers," "determinants," "policy," "acceptability," and "food system" were used in combination with Southeast Asian country identifiers. Manual screening of reference lists from relevant studies was also conducted to identify additional eligible articles.

The review applied the Population–Concept–Context (PCC) framework. The population included children targeted by iron fortification programs, including infants, preschool children, and school-aged children. The concept focused on food system determinants influencing the implementation and success of iron fortification programs, including governance, supply chains, accessibility, compliance, acceptability, and program sustainability. The context was limited to Southeast Asian countries, with particular relevance to Indonesia.

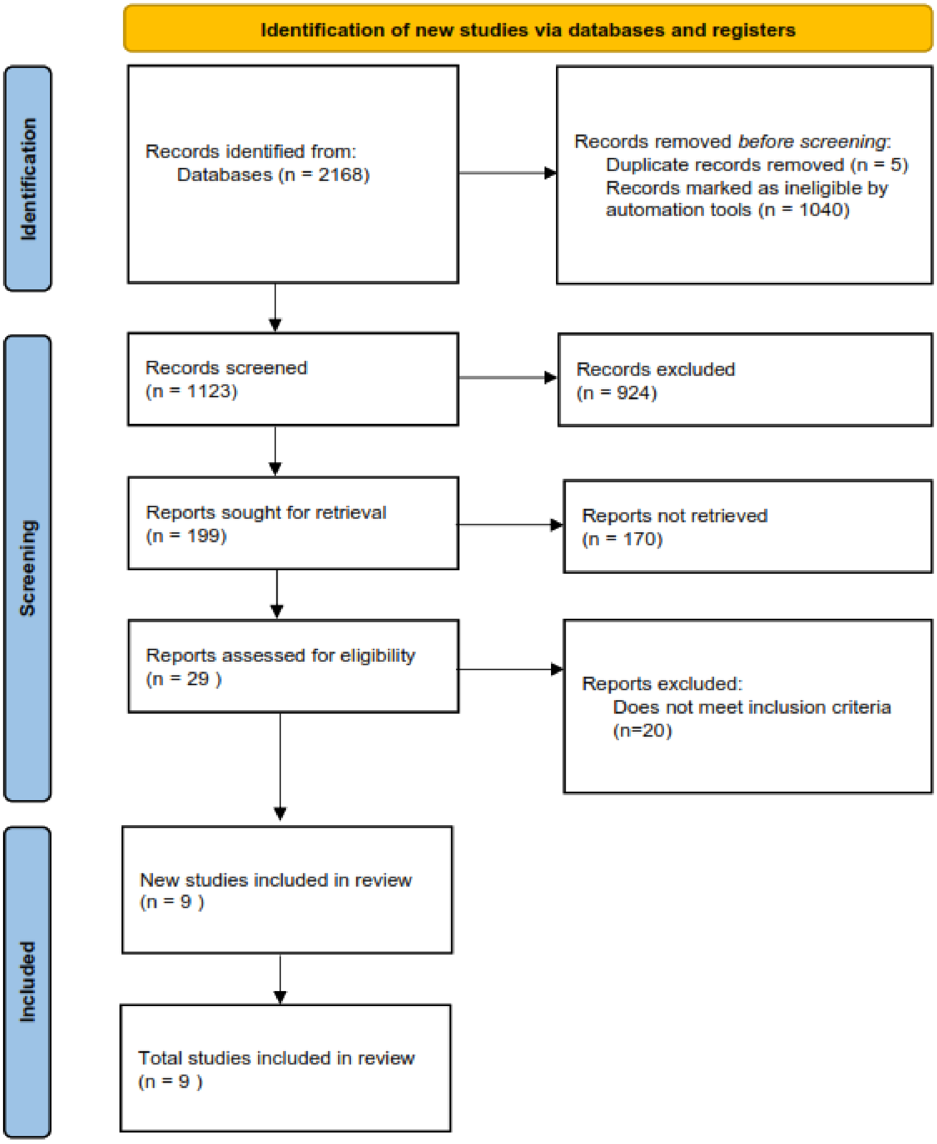

Figure 1. PRISMA Flow Diagram

Studies published between 2015 and 2026 were considered eligible for inclusion if they examined iron fortification interventions among children, reported implementation-related determinants or program outcomes, and were conducted in Southeast Asia. Quantitative, qualitative, mixed-methods, and implementation studies published in peer-reviewed journals in English were eligible for inclusion. Eligible primary studies included randomized controlled trials, cluster randomized trials, quasi-experimental studies, community-based interventions, qualitative studies, and program evaluation studies related to iron fortification programs among children in Southeast Asia. Systematic reviews, meta-analyses, scoping reviews, editorials, conference abstracts, and study protocols were excluded.

All identified records were imported into reference management software, and duplicate articles were removed. Title and abstract screening, followed by full-text assessment, were independently conducted by two reviewers based on predefined eligibility criteria. Disagreements were resolved through discussion. Data extracted from included studies comprised author, year, country, study design, intervention type, target population, implementation determinants, and key findings related to program success.

Due to heterogeneity in study design, intervention type, and reported outcomes, meta-analysis was not performed. Findings were synthesized narratively using a food systems perspective to identify common barriers, facilitators, and determinants influencing the success of iron fortification programs among children in Southeast Asia. The methodological quality of included studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Tools according to study design. Randomized controlled trials were evaluated using the JBI Checklist for Randomized Controlled Trials, whereas quasi-experimental and community-based intervention studies were assessed using the corresponding JBI appraisal tools. Two reviewers independently conducted the quality assessment, and disagreements were resolved through discussion. Studies were not excluded based on quality scores. Quality appraisal findings were considered during data interpretation and synthesis.

Results and Discussion

A total of nine studies met the eligibility criteria and were included in this systematic review **(Table 1).** Primarily conducted in Cambodia and Indonesia, the studies included in this review were randomized controlled trials, cluster-randomized trials, quasi-experimental studies, and community-based interventions that assessed iron or multi-micronutrient fortification programs for children and adolescents. Most interventions utilized fortified staple foods or culturally adapted fortified products, including fortified rice, synbiotic milk, Bose corn, and fortified jelly candy. Across studies, the effectiveness of iron fortification programs was influenced by multiple interconnected determinants, including school feeding systems, dietary adherence, cultural acceptability, caregiver practices, inflammation, gut microbiota, and implementation sustainability.

The methodological quality of the included studies was assessed using the JBI Critical Appraisal Tools according to study design **(Table 2)**. Overall, most studies demonstrated moderate-to-high methodological quality. Randomized controlled trials generally showed low risk of bias due to appropriate randomization procedures, allocation procedures, and outcome assessment. Quasi-experimental and community-based intervention studies presented moderate risk of bias, mainly related to the absence of random allocation and potential confounding factors. No study was excluded based on quality assessment results; however, methodological quality was considered during data interpretation and synthesis.

The findings indicate that the success of iron fortification programs among children in Southeast Asia is influenced by several interconnected food system determinants. The most frequently reported determinants include effective school feeding delivery systems, high intervention adherence, cultural acceptability of fortified foods, supportive caregiver practices, adequate iron absorption in the absence of inflammation and infection, favorable gut health conditions, and sustainable program implementation mechanisms. These determinants collectively influence the effectiveness, uptake, and long-term impact of iron fortification interventions across different settings.

One of the most consistent findings across the included studies was the effectiveness of fortified rice delivered through school feeding programs. Cambodian studies demonstrated that school-based iron fortification interventions improved micronutrient status, hemoglobin concentrations, and cognitive outcomes among schoolchildren. Fiorentino et al. (2015) reported that iron-fortified rice integrated into school meals improved cognitive performance and school functioning among Cambodian schoolchildren.[39] Similarly, Perignon et al. (2016) found that multi-micronutrient fortified rice significantly improved vitamin A status and modestly improved hemoglobin concentrations.[40] These findings were further supported by

Fiorentino et al. (2017), who demonstrated improvements in block design cognitive scores following fortified rice consumption.[41]

Table 1. Characteristic of Studies

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation on Determinants	Key Findings Related to Program Success
1	Fiorentino et al. (2015)[39]	Rice Fortified with Iron in School Meals Improves Cognitive Performance in Cambodian School Children	Cambodia	Double-blind cluster-randomized controlled trial	Iron-fortified rice integrated into school meal programs	Schoolchildren participating in World Food Programme (WFP) school meal program	Iron status, school feeding implementation, micronutrient interactions	Cognitive performance improved significantly in all children after 6 months of fortified rice consumption ($p<0.001$). Children receiving iron-fortified rice without vitamin A showed greater improvement in Block Design cognitive scores than those receiving fortified rice with vitamin A ($p<0.001$) and

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
								controls (p=0.022). Cognitive performance was also significantly associated with iron status and stunting (p<0.05).
2	Perignon et al. (2016)[40]	Impact of Multi-Micronutrient Fortified Rice on Hemoglobin, Iron and Vitamin A Status of Cambodian Schoolchildren: a Double-Blind Cluster-Randomized Controlled Trial	Cambodia	Double-blind cluster-randomized controlled trial	Multi-micronutrient fortified rice distributed through school meal programs	2440 schoolchildren aged 6–16 years	School feeding systems, micronutrient composition, inflammation, implementation coverage	Multi-micronutrient fortified rice improved vitamin A status. Children receiving Multi-micronutrient fortified rice had 4–5 times lower risk of low vitamin A status compared with placebo.

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
								Hemoglobin increased significantly by 0.8 g/L after 3 months (p<0.05).
3	Fiorentino et al. (2017)[41]	Effect of multi-micronutrient-fortifi ed rice on cognitive performance depends on premix composition and cognitive function tested: results of an effectiveness study in Cambodian schoolchildren	Cambodia	Double-blind randomized controlled trial	Multi-micronutrient fortified rice (UltraRice® and NutriRice®)	1796 schoolchildren aged 6–16 years	School meal delivery, cognitive function, parasite infestation, inflammation, stunting	Fortified rice significantly improved cognitive performance. Improvement in block design scores was significantly greater than placebo and other fortified rice groups (p=0.03). All cognitive test scores improved over the 6-month intervention

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
								period (p<0.001).
4	Toruntju et al. (2017)[42]	Study of Hemoglobin and Ferritin Profile as Indicators in Children Hematology of 12-15 Years Provided Local Rice Fortification	Indonesia	Double-blind randomized controlled trial	Local rice fortification with six micronutrients	64 Male students aged 12–15 years	Micronutrient adequacy, school feeding implementation, long-term intake	Consumption of six-micronutrient fortified rice for 6 months increased mean hemoglobin levels from 11.80 g/dL (baseline) to 12.21 g/dL (endline) among anemic adolescents. Ferritin levels increased substantially at midline (38.50 to 78.28 µg/L) before declining at endline. The greatest hemoglobin

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
								improvement was observed among participants aged 12–15 years.
5	Helmyati et al. (2021)[43]	Synbiotic Fermented Milk with Double Fortification (Fe-Zn) as a Strategy to Address Stunting: A Randomized Controlled Trial among Children under Five in Yogyakarta, Indonesia	Indonesia	Double-blind randomized controlled trial	Synbiotic fermented milk fortified with iron and zinc	94 stunted children under five years	Functional food innovation, nutrient fortification, dietary intake, child growth support	Double-fortified synbiotic milk improved nutritional indicators and showed potential benefits for child growth.
6	Gasong et al. (2022)[44]	Formulation and Effect of Iron Fortified Instant Bose	Indonesia	Pre-post controlled intervention study	Iron-fortified instant Bose corn	40 anemic adolescent girls aged 16–19 years	Local food utilization, cultural acceptability,	Fortified Bose corn significantly improved

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
		Corn on Addressing Anemia among Adolescent Girls in Kupang, Indonesia			(traditional Timorese food)		accessibility, adherence, food preparation practicality	hemoglobin levels by 1.73 ± 1.21 g/dL in anemic adolescent girls (p<0.05) and demonstrated high acceptability as a culturally appropriate local food-based intervention (127,4%).
7	Megawati et al. (2023)[45]	The Effect of Jelly Candy Snake Fruit and Banana With Ferrous Fumarat Fortified using Nano Technology in Adolescent	Indonesia	Quasi-experimental pretest–posttest control group study	Ferrous fumarate nano-fortified jelly candy made from snake fruit and banana	150 adolescent girls aged 12–18 years	Compliance, acceptability, nutritional status, menstrual duration, sensory barriers to iron intake	Fortified jelly candy significantly increased hemoglobin levels (p<0.05) and improved adherence to iron intake. Compliance was

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
		Female at Junior High School						identified as a major determinant influencing anemia outcomes.
8	Seyoum et al. (2024)[46]	Faecal microbiota of schoolchildren is associated with nutritional status and markers of inflammation: a double-blinded cluster-randomized controlled trial using multi-micronutrient fortified rice	Cambodia	Double-blind cluster-randomized controlled trial	Multi-micronutrient fortified rice distributed through school feeding programs	380 schoolchildren aged 6–14 years	Nutritional status, inflammation, gut microbiota, school feeding delivery systems	Fortified rice improved micronutrient status and reduced anemia prevalence, although intervention effects varied according to inflammation and microbiota composition.
9	Helmyati et al. (2026)[47]	The Efficacy of Fortified Rice Consumption on Nutritional	Indonesia	Double-blind randomized controlled trial	Fortified rice enriched with vitamins and minerals	96 stunted children aged 12–59 months	Maternal self-efficacy, feeding practices,	Fortified rice significantly increased HAZ by 2.91 points

No	Author (Years)	Title	Country	Study Design	Intervention Type	Target Population	Implementation Determinants	Key Findings Related to Program Success
		Status of Stunted Children Less Than Five Years Old in Yogyakarta, Indonesia					energy intake, compliance	among children aged 4–5 years whose mothers had high self-efficacy (p=0.003). Additionally, 10 children in the fortified rice group improved from stunted to normal nutritional status compared with 7 children in the control group.

Table 2.Risk of Bias Assessment of Included Studies Using JBI Critical Appraisal Tools

No	Study	Study Design	Randomization / Allocation	Group Comparability	Outcome Measurement	Follow-up Completeness	Statistical Analysis	Overall Quality
1	Fiorentino et al. (2015)[39]	Double-blind cluster-randomized controlled trial	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	High
2	Perignon et al. (2016)[40]	Double-blind cluster-randomized controlled trial	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	High
3	Fiorentino et al. (2017)[41]	Double-blind randomized controlled trial	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	High
4	Toruntju et al. (2017)[42]	Double-blind randomized controlled trial	Low Risk	Moderate Risk	Low Risk	Moderate Risk	Low Risk	Moderate
5	Helmyati et al. (2021)[43]	Double-blind randomized controlled trial	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	High
6	Gasong et al. (2022)[44]	Pre-post controlled intervention study	Moderate Risk	Moderate Risk	Low Risk	Low Risk	Low Risk	Moderate
7	Megawati et al. (2023)[45]	Quasi-experimental pretest–posttest control group study	Moderate Risk	Moderate Risk	Low Risk	Low Risk	Low Risk	Moderate
8	Seyoum et al. (2024)[46]	Double-blind cluster-randomized controlled trial	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	High
9	Helmyati et al. (2026)[47]	Double-blind randomized controlled trial	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	High

The positive effects observed in these studies may be explained by the regularity and consistency of nutrient exposure provided through school feeding systems. Iron fortification delivered through daily school meals increases the likelihood of sustained intake, which is essential because iron repletion requires continuous consumption over time.[48,49] Moreover, rice serves as an ideal fortification vehicle in Southeast Asia because it is consumed routinely across socioeconomic groups.[50] Previous evidence supports the effectiveness of fortified staple foods integrated into institutional feeding programs, particularly in settings with high anemia prevalence and limited dietary diversity.[51] Structured school feeding systems improve intervention coverage, adherence, and monitoring, thereby enhancing the overall effectiveness of fortification programs.[52,53] However, despite the positive findings, several studies reported that improvements in hemoglobin and micronutrient status varied across studies depending on baseline nutritional status, inflammatory conditions, intervention duration, and implementation context. Perignon et al. (2016) observed that inflammation reduced the effectiveness of fortified rice interventions.[40] Likewise, Fiorentino et al. (2017) reported that parasite infestation, chronic undernutrition, and inflammation negatively affected cognitive and nutritional outcomes.[41] Seyoum et al. (2024) further demonstrated that the impact of fortified rice varied according to gut microbiota composition and inflammatory status among schoolchildren.[46]

These findings are biologically plausible because iron metabolism is strongly influenced by inflammation and infection. During chronic inflammation, increased hepcidin production inhibits intestinal iron absorption and reduces iron mobilization from body stores, thereby limiting the effectiveness of oral iron interventions.[54,55] Recent studies reported that inflammation, environmental enteric dysfunction, and poor gut health may attenuate the effectiveness of iron supplementation and fortification programs among children in low-resource settings.[56,57] Furthermore, emerging evidence suggests that excess unabsorbed iron in the gastrointestinal tract may alter gut microbiota composition by promoting the growth of pathogenic enterobacteria while reducing beneficial bacteria such as *Lactobacillus* and *Bifidobacterium*. This may partially explain why some fortification interventions produce inconsistent outcomes despite adequate iron delivery.[58,59]

Nevertheless, findings regarding the interaction between iron fortification and gut microbiota remain inconsistent across studies. Earlier studies suggested that iron fortification may increase gut inflammation and pathogenic bacterial growth, particularly in environments with poor sanitation.[60] In contrast, a study conducted in rural Bangladesh reported subtle reductions in beneficial bacteria were still observed.[57] These contradictory findings indicate that the effects of iron fortification on gut health may depend on several contextual factors, including baseline nutritional status, sanitation conditions, infection burden, iron dosage, and formulation bioavailability. Consequently, future fortification strategies should consider not only nutrient efficacy but also microbiological safety and gastrointestinal tolerance.[61]

Another important determinant influencing intervention success was cultural acceptability and integration within local food systems. Gasong et al. (2022) demonstrated that iron-fortified instant Bose corn, a traditional Timorese food, significantly improved hemoglobin levels among adolescent girls while maintaining high acceptability.[44] Similarly, Megawati et al. (2023) found that nano-fortified jelly candy significantly increased hemoglobin levels and improved adherence to iron intake among adolescent girls. Compliance was identified as one of the strongest determinants influencing anemia outcomes.[45]

These findings highlight the importance of sensory characteristics and cultural familiarity in determining adherence to iron interventions. Conventional iron supplementation programs frequently encounter poor compliance because of metallic taste, gastrointestinal side effects, nausea, and unpleasant odor.[62,63] By contrast, food-based fortification strategies may improve adherence because they are incorporated into familiar dietary practices and are perceived as regular foods rather than medicinal products.[64,65] Recent food systems research emphasizes that culturally acceptable fortified foods are more likely to achieve sustained community uptake and long-term behavioral integration. This is particularly relevant in Southeast Asia, where dietary preferences and staple food consumption patterns differ substantially across regions.[66]

The use of locally available food vehicles may also improve program sustainability and accessibility. Gasong et al. (2022) utilized fortified Bose corn, a traditional local food commonly consumed in East Nusa Tenggara, thereby reducing dependence on imported commercial products.[44] Such approaches align with contemporary food systems frameworks advocating for the utilization of local food resources to strengthen both nutrition outcomes and local food economies.[67] In Indonesia, where food diversity and regional dietary patterns are highly heterogeneous, locally adapted fortification strategies may be more feasible and acceptable than centralized standardized interventions. Long-term sustainability of fortification programs also requires supportive financing mechanisms and multisectoral partnerships. Recent evidence has highlighted the potential role of philanthropic organizations, public-private partnerships, and community-based initiatives in strengthening the sustainability of nutrition interventions and food system transformation efforts.[68]

In addition to acceptability, caregiver-related factors also substantially influenced intervention outcomes.[69,70] Helmyati et al. (2026) found that fortified rice improved height-for-age trends among stunted children, particularly among children whose mothers demonstrated strong self-efficacy and appropriate feeding practices.[47] This finding aligns with behavioral research from Indonesia demonstrating that caregiver intentions, perceived behavioral control, and health beliefs significantly influence anemia prevention behaviors and adherence to nutrition interventions.[71] Similarly, Helmyati et al. (2021) reported improvements in nutritional indicators among stunted children receiving double-fortified synbiotic milk. However, no statistically significant differences were observed between groups. This finding may be explained by the provision of synbiotic milk to both intervention and control groups, which could have contributed to nutritional improvements irrespective of additional iron and zinc fortification.[43] The findings of this review are also consistent with recent Indonesian evidence emphasizing the importance of addressing anemia across the life course. Basrowi et al. (2024) highlighted that maternal anemia contributes to adverse offspring health outcomes, reinforcing the need for integrated iron deficiency prevention strategies beyond childhood interventions alone.[11] Similarly, Sungkar et al. (2022) advocated a life-course approach to anemia prevention, emphasizing that childhood nutrition interventions should be integrated with maternal, adolescent, and reproductive health programs to achieve sustainable reductions in anemia prevalence.[72]

The relatively modest growth improvements observed in these studies likely reflect the multifactorial etiology of stunting and anemia. Iron deficiency is only one component contributing to impaired growth. Child growth is also influenced by protein intake, recurrent infections, environmental sanitation, caregiving quality, dietary diversity, and socioeconomic conditions.[73,74] Consequently, iron fortification alone may be insufficient to substantially improve linear growth without simultaneous improvements in broader nutritional and environmental determinants.[75] This explanation is supported by recent systematic reviews demonstrating that multi-component nutrition interventions combining micronutrient delivery, dietary counseling, infection control, and caregiver education are generally more effective in improving child growth outcomes than single-nutrient approaches alone.[76–78]

Another important observation from this review was that multi-micronutrient fortification appeared to produce broader benefits than iron-only interventions. Several included studies utilized fortified rice enriched with iron alongside vitamin A, zinc, folate, and vitamin B complex. Improvements were observed not only in anemia indicators but also in cognitive performance, vitamin A status, and nutritional outcomes.[40,41,47] This finding is consistent with current evidence suggesting that micronutrient deficiencies frequently coexist in children from low- and middle-income countries.[22,79] Iron deficiency rarely occurs in isolation and is often accompanied by deficiencies in zinc, folate, and vitamin A, all of which contribute to impaired immunity, cognitive development, and growth.[80,81]

From a policy perspective, the findings of this review suggest that successful iron fortification programs require a comprehensive food systems approach rather than solely focusing on nutrient delivery. Effective implementation depends on strong school feeding infrastructure, culturally acceptable food vehicles, sustained adherence, caregiver engagement, and integration with infection control and public health interventions. In Indonesia, rice fortification represents a highly promising strategy because rice is consumed daily by nearly all population groups.[82,83] However, implementation challenges remain substantial, including uneven distribution systems, affordability barriers, limited quality monitoring, and regional differences in food preferences.[33]

Recent policy analyses emphasize that food fortification programs are most effective when integrated into broader social protection and nutrition systems.[84] Fortified rice integrated into school feeding programs, maternal-child nutrition initiatives, and food assistance schemes may improve coverage among nutritionally vulnerable populations while simultaneously strengthening implementation sustainability.[82] Moreover, supporting locally produced fortified foods may contribute not only to nutritional improvement but also to regional food security and economic resilience.[67]

Indonesia possesses considerable potential for scaling up fortified rice programs because rice is consumed daily by almost the entire population. However, implementation challenges remain substantial, including uneven distribution systems, affordability barriers, monitoring limitations, and variations in regional dietary practices. Integrating fortified foods into existing social protection and school feeding programs may improve program reach and sustainability, particularly among nutritionally vulnerable populations. Furthermore, leveraging locally produced fortified foods may support both nutritional improvement and local agricultural economies.

Overall, this review demonstrates that the success of iron fortification programs among children in Southeast Asia is shaped by complex interactions between biological, behavioral, cultural, and food system determinants. Although iron fortification consistently improved hemoglobin and micronutrient outcomes across many studies, intervention effectiveness was frequently moderated by inflammation, gut health, adherence, caregiving quality, and implementation context. Future programs should therefore adopt integrated food systems strategies that combine iron fortification with culturally appropriate food delivery systems, infection prevention, caregiver education, and multisectoral policy support to achieve sustainable improvements in child nutrition outcomes in Southeast Asia, particularly in Indonesia.

This review has several strengths. First, it is among the first systematic reviews to examine iron fortification programs in Southeast Asia through a food systems lens rather than focusing solely on biological outcomes. Second, the review incorporated diverse study designs, enabling a comprehensive understanding of both intervention effectiveness and implementation determinants. Third, the findings provide context-specific insights relevant to Indonesia and other Southeast Asian countries. Nevertheless, several limitations should be acknowledged. The number of eligible studies was relatively limited and concentrated primarily in Cambodia and Indonesia, potentially restricting regional generalizability. Considerable heterogeneity in intervention types, fortified food vehicles, outcome measures, and implementation contexts precluded quantitative meta-analysis. In addition, publication bias may exist because only English-language peer-reviewed studies were included.

Conclusion

This systematic review demonstrates that the success of iron fortification programs among children in Southeast Asia is influenced not only by nutrient delivery, but also by broader food system determinants, including school feeding systems, cultural acceptability, adherence, caregiver practices, inflammation, and implementation sustainability. Fortified rice and other culturally adapted fortified foods consistently improved hemoglobin levels, micronutrient status, and cognitive outcomes, particularly when integrated into structured feeding programs and familiar dietary patterns. However, intervention effectiveness was frequently limited by inflammation, infections, poor sanitation, low adherence, and uneven program implementation. These findings highlight that iron fortification alone may be insufficient without simultaneous improvements in public health, caregiver education, and food system support. For Indonesia, fortified rice and locally adapted fortified foods represent promising strategies due to high staple food consumption and regional food diversity. Future policies should therefore adopt integrated food systems approaches that strengthen accessibility, acceptability, governance, and multisectoral collaboration to achieve sustainable reductions in childhood iron deficiency and improve child growth outcomes.

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Conflict of Interest

There are no conflict interest of this publication.

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