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OPTIMIZING IRON ABSORPTION IN CHILDREN THROUGH VITAMIN C SUPPLEMENTATION AND FORTIFICATION: A REVIEW

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Abstract

Background: Iron deficiency aeamia is common in children, particularly in low- and middle-income countries, where diets are typically low in bioavailable iron and infections are prevalent. As vitamin C enhances non-heme iron absorption, this review explores current evidence on its role in improving iron status in children. **Methods**: A narrative literature review was conducted using PubMed, Scopus, and Google Scholar and included studies published from January 2000 to June 2025. Search terms combined keywords related to “vitamin C”, “iron absorption”, “supplementation”, “fortification”, “children”, and “anemia”. **Results:** Iron absorption in children is influenced by iron form, dietary factors, and developmental stage, with infants and young children at greatest risk of deficiency. Vitamin C is an enhancer of non-heme iron absorption, counteracting inhibitors such as phytates and calcium. Trials combining oral iron with vitamin C supplementation generally showed greater increases in hemoglobin and ferritin compared with iron alone, particularly among children with iron deficiency. Evidence from fortification studies is limited and varies due to differences in study design. **Conclusion:** Vitamin C co-supplementation might improve iron status in children. However, existing evidence remains insufficient to support specific recommendations for children.

Keywords: Iron bioavailability, vitamin C, food fortification, supplementation, childhood anemia

Introduction

Iron deficiency is the most common micronutrient deficiency and a leading cause of anemia in children.[1] Iron deficiency anemia (IDA) has been linked to impaired cognitive development, weakened immune function, and poor growth outcome.[2-4] Globally, an estimated 16–40% of children under five are affected, with the highest burden in Asia and sub-Saharan Africa. [5, 6]

IDA in young children arises primarily from inadequate dietary intake combined with increased iron requirements during periods of rapid growth.[7] The condition is especially prevalent among children with poor or selective eating habits and in low- and middle-income countries (LMICs), where diets are largely plant-based and dominated by non-heme iron sources with inherently low bioavailability. Gastrointestinal (GI) conditions such as mucosal disorders, *Helicobacter pylori* infection, and hypochlorhydria may further compromise absorption.[8]

Iron supplementation remains the standard intervention for treating IDA;[9] however, its effectiveness can be limited by poor absorption, low adherence, and GI side effects.[10] Growing evidence suggests that enhancing iron bioavailability is as crucial as supplementation itself. Vitamin C, a well-recognized enhancer, improves iron uptake by reducing ferric iron (Fe^{3+}) to the more absorbable ferrous form (Fe^{2+}), forming soluble complexes that improve uptake in the GI tract.[11] While these mechanisms are well established in biological studies, their practical significance in human populations remains to be fully understood.

This review synthesizes current evidence on the role of vitamin C in improving iron absorption in children, with a focus on underlying mechanisms, dietary interactions, and intervention strategies in public health settings.

Method

A narrative literature review was conducted to examine the role of vitamin C in enhancing iron absorption among children. We included experimental, observational, and programme-based studies relevant to public health nutrition. The review explored three main areas: (1) the physiological mechanisms of vitamin C in iron metabolism in children (2) dietary factors affecting iron bioavailability, and (3) intervention strategies involving vitamin C supplementation and food fortification, focusing on both controlled trials and pre–post intervention studies to capture a broader range of evidence, particularly in resource-limited settings.

The literature search was conducted using PubMed, Scopus, and Google Scholar, covering articles published from January 2000 to June 2025. Keywords and MeSH terms were combined using Boolean operators, including: “vitamin C” or “ascorbic acid”, “iron absorption” or “iron bioavailability”, “children” or “pediatric” or “infant”, “supplementation”, “fortification”, “anemia” or “iron deficiency”. Additional studies were identified through manual screening of reference lists from relevant articles.

Results and Discussion

Physiology of Iron Absorption in Children

The absorption of iron occurs in the small intestine, mainly in the proximal part. Since the human body lacks a dedicated mechanism for excreting excess iron, iron homeostasis is maintained by regulation of iron absorption. Several proteins are involved in coordinating the transfer of iron across enterocytes into the bloodstream. Most notably, these proteins include divalent metal transporter-1 (DMT1), ferroportin (FPN), and transferrin receptors (Tfrs) in conjunction with ferroxidases like duodenal cytochrome B (Dcytb).[12]

Iron is obtained from the diet as heme iron and non-heme iron. Heme iron is absorbed directly via the heme carrier protein 1 (HCP1) into enterocytes, where it is subsequently broken down by heme oxygenase to release ferrous iron (Fe^{2+}). Non-heme iron is mostly present in the ferric (Fe^{3+}) form. Prior to absorption, it must be reduced to the ferrous (Fe^{2+}) form by duodenal cytochrome B (Dcytb), a ferric reductase enzyme located on the apical membrane of enterocytes. The ferrous iron is then transported across the membrane by divalent metal transporter 1 (DMT1).[13]

Iron absorption from food depends on the form of iron not the amount of iron content.[14] In a mixed diet containing both heme and non-heme iron, the overall availability of iron is about 14–18%. Heme iron which is found in animal food sources, may contributes only around 15% of total iron intake but can account for more than 40% of total intestinal iron absorption.[15] On the other hand, non-heme iron found in plant sources and fortified products has a lower absorption rate of about 2–9%.[16]

Dietary factors can enhance or inhibit non-heme iron absorption. A number of complexes, particularly phytates and tannins might impede absorption through chemical binding,[17] while the presence of 'meat factor' from animal products increases iron bioavailability.[18] Other factor that improves absorption is acidic condition which enhances solubilization of non-heme iron. Vitamin C (ascorbic acid) incorporation has been shown to enhance absorption by forming a chelate with ferric iron in the stomach that remains soluble at the alkaline pH of the duodenum.[11] In addition, vitamin C may reverse the inhibitory effect of phytic acid and sodium oxalate on iron absorption.[19]

Lönnerdal et al.[20] have discussed the physiology of iron absorption and regulation in infants, highlighting that while the molecular mechanisms controlling iron homeostasis have been thoroughly detailed for adults, little is known about how this regulation functions and what age it occurs at in infants. However, according to more recent research, iron absorption in neonates seems to start rising at threshold ferritin and hepcidin levels of around 46 µg/L and 3 nmol/L, respectively, which are comparable to adult levels.[21] Nevertheless, intestinal FPN shows a decreased reactivity to hepcidin during suckling, suggesting that there may be variations in the mechanism of intestinal iron absorption in suckling newborns.[13] Infants aged 9–24 months are at greatest risk of iron deficiency due to rapid growth and inadequate intake from complementary foods. IDA is also common among children with poor diets, pica, or avoidance of iron-rich foods. In school-aged children, prevalence is lower, and most cases were due to blood loss from epistaxis or gastrointestinal conditions.[22]

Supplementation and Fortification Strategies

Supplementation and fortification with vitamin C alongside iron have been explored as potential strategies to improve iron absorption and reduce anemia in children. The optimal dosage of vitamin C supplementation to enhance iron absorption has not been firmly established, but studies that provided 25–250 mg of vitamin C together with oral iron have shown improvements in iron status.[23-26] Age-appropriate dosing is essential in children, and vitamin C should ideally be provided through food-based sources or low-dose supplements rather than high-dose tablets to minimise the risk of gastrointestinal discomfort.[27]

The effectiveness of vitamin C in fortification programmes depends on formulation, stability, and the iron compound used. Milk-based fortification has shown the strongest real-world impact, largely because milk provides a relatively stable matrix for both iron and vitamin C. By contrast, cereal- and soy-based strategies have been less successful due to the degradation of vitamin C during processing and storage, as well as the high phytate and polyphenol content of these foods, which significantly reduce iron bioavailability.[28]

There are limited trials investigating the combination of iron and vitamin C supplementation in the pediatric population over the last decades. In those studies, iron and vitamin C were given in the form of either ferrous ascorbate or oral iron (ferrous sulfate, ferrous fumarate, ferrous succinate) combined with oral vitamin C.[23-26] Evidence on vitamin C fortification is even more limited, with only a few recent studies available. Reported outcomes have primarily focused on changes in iron biomarkers, anemia prevalence, and growth and developmental indicators (Table 1).

Table 1. Summary of studies investigating the effect of vitamin C supplementation or fortification in enhancing iron absorption in children

Author (Year)	Study design	Study Population (Country)	Intervention	Comparison	Dura-tion	Main findings
Putra et al. (2025)[23]	Control-led trial	52 adolescent girls aged 12-13 years with Hb levels 7-12 g/dL (Indonesia)	Ferrous fumarate 60 mg + folic acid 0.4 mg) + vitamin C (250 mg), once a week	Ferrous fumarate 60 mg + folic acid 0.4 mg), once a week	4 weeks	• The mean increase of hemoglobin levels was significantly higher in the intervention vs control group (2.25 g/dL vs 0.69 g/dL, $p < 0.05$).

Author (Year)	Study design	Study Population (Country)	Intervention	Comparison	Dura-tion	Main findings
Astuti et al. (2018)[24]	RCT	22 adolescent girls aged 13-14 years with Hb level 8-12 g/dL (Indonesia)	Ferrous sulfate + vitamin C (up to 100 mg daily)	Ferrous sulfate	6 months	• Serum ferritin level was higher in the intervention than in control groups after the treatment (41.89 ± 13.18 vs 27.58 ± 6.48, *p* = 0.004).
Patil et al. (2019)[25]	RCT	125 children aged 1–12 years having clinical symptoms and signs of anemia (India)	Ferrous ascorbate (FA) containing 6 mg/kg elemental iron	Iron polymaltose complex (IPC) containing 6 mg/kg elemental iron	3 months	• The difference in Hemoglobin (g%) at the end of intervention in FA group (4.88 ± 1.28) vs. IPC group (3.33 ± 1.33); *p* = 0.001 was statistically significant.
Yewale et al. (2013)[26]	RCT	73 children aged 6 months to 12 years (India)	Ferrous ascorbate suspension with 30 mg elemental Iron (5 mL)	Colloidal iron suspension with 80 mg elemental iron (5 mL)	12 weeks	• The mean rise in Hb was significantly higher in ferrous ascorbate group than the colloidal iron group [3.59 ± 1.67 g/dl *vs*. 2.43 ± 1.73 g/dl; *p* < 0.01]. • Significantly higher proportion of children who received ferrous ascorbate vs colloidal iron became non-anemic (64.86 % *vs*. 31.03 %; *P* < 0.01)
Angeles-Agdeppa et al. (2012)[29]	RCT	76 anemic children aged 5-8 years (Phillipines)	Oat drink fortified with iron (3.25mg NaFeEDTA), zinc (2.34mg zinc oxide), vitamin A (225mcg RE), and vitamin C (45mg).	Oat drink without fortifica-tion	120 days	• Prevalence of anemia decreased by 68%
Rocha et al. (2011)[30]	Pre-post interve ntion	318 children aged 6 to 74 months in day care centers (Brazil)	Water fortification with 5 mg of elemental iron + 50 mg of	N/A	5 months	• The prevalence of anemia decreased from 29.3% to 7.9% • Hemoglobin levels increased from 11.8 ±

Author (Year)	Study design	Study Population (Country)	Intervention	Comparison	Dura-tion	Main findings
			ascorbic acid per liter.			1.3 to 12.4 ± 0.93 g/dL (p <0.01) • Mean height-for-age z-score increased from –0.39 ± 1.1 to –0.31 ± 1.0 (p <0.001)

The studies summarized in this review show generally positive outcomes. Trials conducted in Indonesia and India reported greater increases in haemoglobin or ferritin levels among children receiving vitamin C alongside iron compared with iron alone.[23–26] These effects were particularly notable in aaemic or iron-deficient participants, suggesting that vitamin C may be more beneficial in populations with poor baseline iron status. Evidence from food fortification studies, such as those using oat drinks in the Philippines or fortified water in Brazil, also showed reductions in anaemia prevalence.[29,30] However, differences in study design, population, baseline iron levels, and the amount of vitamin C used make it difficult to draw firm conclusions. Most studies were also short-term and focused on absorption rather than long-term changes in blood iron markers.

Knowledge Gaps and Future Recommendation

This review highlights the efficacy of vitamin C in enhancing iron absorption in human subjects. The facilitative role of vitamin C stems from its antioxidant capacity, which helps convert ferric iron to the more absorbable ferrous form, prevents its re-oxidation, and chelates iron to support uptake.[11, 19]

Current guidelines from World Health Organization recommend including vitamin C-rich fruits and vegetables to improve iron bioavailability.[31] Dietary diversity is therefore critical for ensuring adequate intake and absorption of these nutrients in children.[32] Diets that include a balance of animal-source foods and fresh fruits and vegetables provide not only bioavailable iron but also sufficient vitamin C, which facilitates iron absorption.[33] A recent meta-analysis demonstrated that children and adolescents with low dietary diversity had significantly higher odds of anemia (1.96 and 1.73, respectively).[34] When dietary variety is limited, risks of both iron and vitamin C deficiency rise, particularly during periods of rapid growth and development.[35]

Despite studies reporting short term improvement of iron status, evidence is scarce on the long-term outcomes of vitamin C interventions to improve iron absorption in children, especially regarding growth, cognitive development, and overall health. Data are also limited for specific populations, such as toddlers, adolescents, and children in rural or resource-constrained settings, whose dietary patterns and risk factors may differ from those in urban areas. In addition, more implementation research is needed to evaluate the scalability, cultural acceptability, cost-effectiveness, and health system integration of supplementation and fortification programmes.

Although vitamin C is widely recommended with iron, this practice is grounded more in biological plausibility than robust epidemiological evidence. Current data remain insufficient to demonstrate a consistent treatment benefit of vitamin C beyond its role from dietary sources.

Conclusion

Vitamin C has been consistently shown to improve non-heme iron absorption across a variety of foods, particularly by counteracting the inhibitory effects of phytates and calcium. Nevertheless, existing evidence remains insufficient to support specific recommendations for vitamin C co-supplementation to improve iron status in children.

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Conflict of Interest

There is no conflict interest of this publication.

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