Nutritional Insights into Iron Deficiency: Evaluating the Impact of a Vegetarian Diet on Iron Status and Absorption

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Publication Date: 2025/10/30

Abstract: Iron deficiency remains the most prevalent micronutrient disorder globally, affecting nearly two billion people across all age groups. Vegetarian diets, although associated with numerous health benefits, pose nutritional challenges due to their reliance on plant-based sources of non-haem iron, which is less bioavailable than haem iron from animal products. This comprehensive review synthesises global evidence on iron metabolism, the influence of vegetarian diets on iron status, and current and emerging strategies to enhance iron bioavailability. A narrative review approach was used to analyse literature published from 2000 to 2025 across PubMed, Scopus, and Web of Science. Vegetarians consistently exhibit lower ferritin levels and marginally reduced haemoglobin concentrations compared with omnivores, attributed mainly to inhibitory dietary factors such as phytates, polyphenols, and calcium. However, bioavailability can be significantly improved through ascorbic acid intake, food fermentation, and fortification strategies. Innovations like iron-biofortified crops, nanotechnology-based fortification, and plant-derived heme analogues hold promise in mitigating deficiency. Comprehensive nutritional education, fortification policies, and routine screening are essential to address this global concern. Promoting evidence-based dietary strategies can ensure that vegetarian populations achieve optimal iron status without compromising ethical and environmental principles.

Keywords: Vegetarian Diet, Iron Deficiency, Non-Haem Iron, Bioavailability, Phytates, Fortification, Anaemia, Nutrition, Public Health.

How to Cite: Dr. Venugopal Reddy. I.; Dr. Naga Praneeth Raj; Dr. Sachin Padman (2025) Nutritional Insights into Iron Deficiency: Evaluating the Impact of a Vegetarian Diet on Iron Status and Absorption. *International Journal of Innovative Science and Research Technology*, 10(10), 1789-1792. https://doi.org/10.38124/ijisrt/25oct1030

I. INTRODUCTION

Iron is a vital micronutrient required for oxygen transport, cellular respiration, and energy metabolism. Despite its abundance in the environment, iron deficiency anaemia (IDA) remains a major global health problem. The World Health Organization (WHO) estimates that approximately 30% of the world's population suffers from anaemia, with iron deficiency being its leading cause. Vegetarian diets comprising lacto-vegetarian, lacto-ovo-vegetarian, and vegan variations are increasingly popular for ethical, environmental, and health reasons. These diets are rich in fibre, antioxidants, and unsaturated fats but typically lack bioavailable iron due to dependence on plant-based sources. The challenge arises from the predominance of non-haem iron, which is absorbed less efficiently (2–10%) compared to haem iron (15–35%) from meat, poultry, and fish.

Epidemiological studies have demonstrated a strong correlation between vegetarianism and reduced iron stores, particularly among women and children in developing countries. However, with balanced meal planning, use of enhancers such as vitamin C, and awareness of inhibitory food combinations, vegetarians can maintain adequate iron levels. The growing emphasis on plant-based nutrition globally necessitates an in-depth understanding of iron absorption mechanisms and population-level strategies to prevent deficiency.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct1030

II. IRON METABOLISM AND ABSORPTION

Iron metabolism in humans involves complex regulatory pathways balancing absorption, transport, and storage. Dietary iron exists as haem and non-haem forms. Haem iron, derived from haemoglobin and myoglobin in animal foods, is absorbed intact via haem carrier protein-1 (HCP1). Non-haem iron, predominant in plant foods, is absorbed through a multistep process involving reduction, transport, and export.

In the duodenum, ferric iron (Fe^{3+}) is reduced to ferrous iron (Fe^{2+}) by duodenal cytochrome b (Dcytb). The divalent metal transporter 1 (DMT1) facilitates uptake into enterocytes. Within the cell, iron is either stored in ferritin or exported into the circulation by ferroportin. Hephaestin oxidises Fe^{2+} back to Fe^{3+}, enabling binding to transferrin, which transports it to the bone marrow and tissues. Hepcidin, a hepatic peptide hormone, plays a central regulatory role by binding to ferroportin and inducing its degradation, thereby reducing absorption when body iron stores are sufficient.

The diagram below illustrates the intestinal absorption pathway of iron, including the role of Dcytb, DMT-1, ferroportin, and hephaestin. It also highlights key dietary enhancers such as vitamin C and organic acids, and inhibitors including phytates, polyphenols, and calcium. Hepcidin regulates systemic iron homeostasis by controlling ferroportin activity.

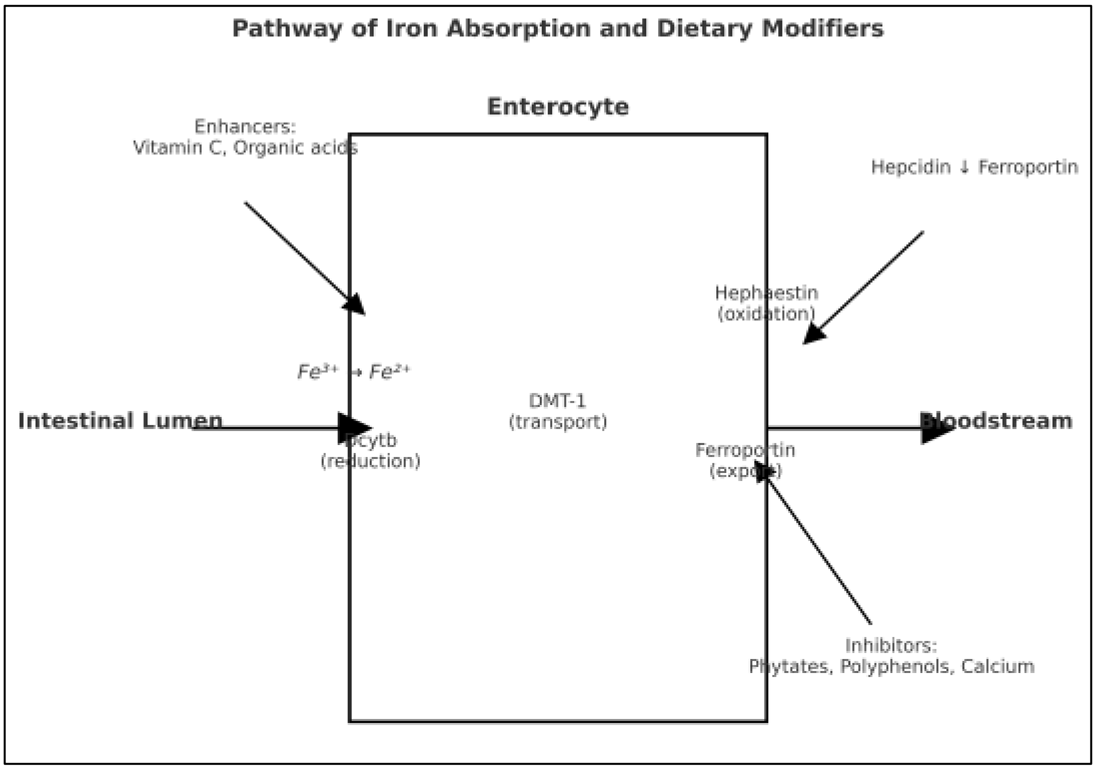

Fig 1 | Pathway of Iron Absorption and Dietary Modifiers

III. IRON STATUS AMONG VEGETARIAN POPULATIONS

Studies consistently reveal lower serum ferritin concentrations among vegetarians compared to omnivores, although clinical anaemia remains uncommon. The EPIC-Oxford study found that 25% of vegetarian women had ferritin levels below 15 µg/L, compared with 10% of non-vegetarian women. Haider et al. (2018) confirmed in a meta-analysis of 24 studies that vegetarians had 32% lower ferritin and 5% lower haemoglobin concentrations than meat-eaters. These findings highlight reduced iron stores but also reflect adaptive physiological mechanisms such as enhanced absorption efficiency and reduced iron loss.

In South Asia, where vegetarianism is culturally prevalent, anaemia remains widespread. The National Family Health Survey (NFHS-5, 2021) reported anaemia in 57% of Indian women aged 15–49 years and 67% of children under five. This high prevalence stems from dietary patterns dominated by cereals and legumes rich in iron absorption inhibitors.

Table 1. Dietary Enhancers and Inhibitors of Iron Absorption

Category	Enhancers	Inhibitors
Nutrient Factors	Vitamin C, Organic acids, β-carotene, Fermentation	Phytates, Polyphenols, Calcium, Oxalates
Food Processing	Soaking, Germination, Fermentation, Sprouting	Refined cereals lacking natural enhancers
Meal Composition	Combining iron-rich foods with fruits/vegetables	Tea, coffee, cocoa with meals
Fortification	Iron-fortified wheat, rice, or salt	Low adoption of fortified foods

IV. DIETARY FACTORS INFLUENCING IRON BIOAVAILABILITY

The absorption of non-haem iron is significantly affected by meal composition. Vitamin C enhances absorption by reducing ferric to ferrous iron and forming soluble complexes. A single 75 mg dose of ascorbic acid can double non-haem iron absorption. Organic acids such as citric, malic, and lactic acid similarly enhance solubility. Traditional Indian foods like idli and dosa, produced through fermentation, degrade phytates, improving iron uptake.

Conversely, phytates found in legumes and whole grains strongly inhibit absorption by binding iron to insoluble complexes. Polyphenols and tannins in tea and coffee inhibit absorption by 50–70% when consumed with meals. Calcium competes with iron at intestinal binding sites, though its long-term inhibitory effect is modest. Understanding these interactions is key to designing nutritionally adequate vegetarian meal plans.

V. PUBLIC HEALTH IMPACT OF IRON DEFICIENCY

Iron deficiency is associated with impaired neurocognitive development, reduced work capacity, and increased morbidity. In pregnant women, it contributes to preterm birth, low birth weight, and elevated maternal mortality. WHO attributes approximately 20% of maternal deaths to anaemia. The economic burden is substantial, with estimated productivity losses exceeding 4% of GDP in developing nations. In India, the government's Anemia Mukt Bharat initiative aims to reduce anaemia prevalence by promoting fortified foods and supplementation.

VI. INTERVENTIONS AND INNOVATIONS

Multiple approaches address iron deficiency among vegetarians. Food fortification is among the most cost-effective. WHO recommends fortifying staple foods such as wheat flour, rice, and salt with ferrous sulphate or NaFeEDTA. Biofortified crops like iron-enriched pearl millet and lentils have demonstrated improved absorption in human studies. Nanotechnology-based fortification using micronised ferric pyrophosphate enhances absorption while maintaining sensory properties. Emerging research on plant-based heme analogues derived from yeast proteins suggests potential to mimic haem iron's bioavailability.

Nutritional counselling remains essential, encouraging vitamin C-rich foods, minimising inhibitors, and promoting the use of cast-iron cookware. Behavioural change communication, public health campaigns, and integration of fortified foods into government nutrition programmes are crucial for sustainable outcomes.

VII. FUTURE DIRECTIONS

Future research should explore microbiome–iron interactions, as certain probiotic strains enhance absorption and mitigate inflammation-induced hepcidin elevation. Nutrigenomics offers insights into genetic polymorphisms affecting iron metabolism, allowing personalised dietary recommendations. Digital tools and artificial intelligence-based nutrition tracking can help monitor iron status and diet quality in vegetarian populations. Sustainable innovations focusing on plant-based fortificants and eco-friendly production methods align with global climate and health goals.

VIII. CONCLUSION

Vegetarianism offers numerous health and environmental advantages but carries inherent risks of iron deficiency if not properly managed. Comprehensive public health strategies encompassing dietary diversification, food fortification, and routine screening can ensure adequate iron status. Education on enhancers and inhibitors of iron absorption, coupled with government-led initiatives, can significantly reduce anaemia prevalence. The integration of advanced nutrition science, biotechnology, and digital health can revolutionise the prevention of iron deficiency globally.

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ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct1030

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