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Popular Article

## Iron Nutrition in Pulse Crops: Physiological, and Molecular Perspectives

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### Abstract

Iron (Fe) is an essential micronutrient that plays a pivotal role in plant metabolism, nodulation, and seed nutritional quality in pulse crops. It is a cofactor in enzymes involved in respiration, photosynthesis, and nitrogen fixation. Deficiency leads to chlorosis, poor nodulation, and reduced yield, while adequate supply enhances seed mineral content and human nutrition. Advances in molecular biology have identified iron transporters, chelators, and regulatory genes that govern uptake and homeostasis, offering opportunities for biofortification. This review synthesizes current knowledge on iron nutrition in pulses, emphasizing physiology, soil management, molecular breeding, and extension strategies for sustainable agriculture and improved dietary iron intake.

### Introduction

Pulse crops such as chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), lentil (*Lens culinaris*), and mung bean (*Vigna radiata*) are vital to food security and vegetarian diets, providing protein, fiber, and micronutrients. Iron deficiency in soils and crops is a widespread challenge, particularly in calcareous and alkaline soils where Fe availability is limited due to precipitation and poor solubility (Marschner, 2012). Iron nutrition in Indian soils and pulse crop farming presents a complex challenge. Although iron is abundant in the earth's crust, its availability to plants is often restricted, particularly in calcareous and alkaline soils where Fe<sup>3+</sup> precipitates into insoluble forms. Surveys indicate that around 11–12% of Indian soils are deficient in available iron, with higher prevalence in states such as Karnataka, Maharashtra,



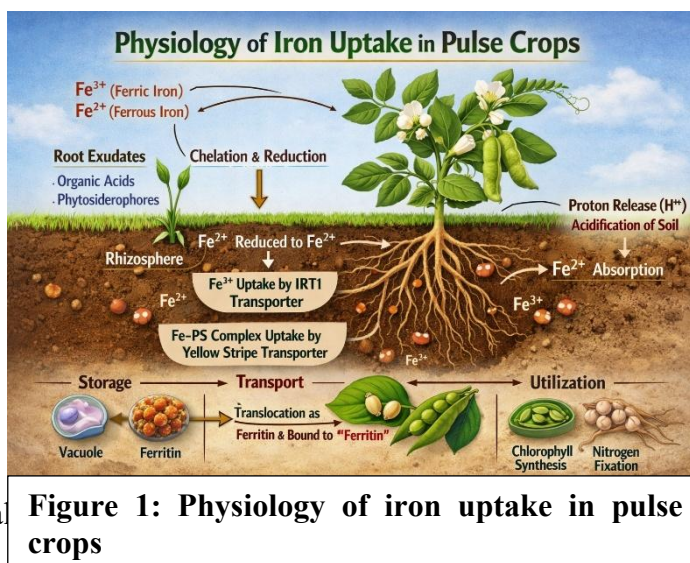
Himachal Pradesh, Haryana, Tamil Nadu, and Punjab. The critical threshold for deficiency is generally considered to be less than 7.5 mg Fe kg<sup>-1</sup> of soil (DTPA-extractable). This widespread deficiency is aggravated by intensive cultivation, imbalanced fertilization, and limited use of organic amendments, all of which reduce the bioavailability of iron to crops.

In pulse crop farming, iron plays a vital role in nodulation and nitrogen fixation, as it is a component of leghemoglobin and nitrogenase enzymes. Deficiency symptoms such as interveinal chlorosis, poor nodulation, and reduced pod set are common in pulse-growing regions, leading to yield losses of up to 16–32%. Beyond agronomic impacts, low iron availability in soils directly reduces seed iron concentration, which is a critical nutritional concern in India where pulses are a major dietary source of iron for vegetarian populations. This contributes to hidden hunger and iron-deficiency anemia, a widespread public health issue. Addressing iron nutrition in pulses therefore requires integrated strategies, including soil amendments with iron chelates, foliar sprays for rapid correction, organic inputs to improve rhizosphere mobilization, and molecular breeding approaches for biofortification. Together, these interventions can strengthen both crop productivity and human nutrition security in India.

In legumes, Fe is indispensable for symbiotic nitrogen fixation, as it forms part of leghemoglobin and nitrogenase enzymes (Guerinot & Yi, 1994). Deficiency manifests as interveinal chlorosis, poor nodulation, and reduced seed quality, directly impacting productivity and nutritional outcomes. Addressing Fe nutrition in pulses is therefore critical for both agricultural sustainability and combating iron deficiency anemia in human populations.

### Physiology of Iron uptake in Pulse Crops

Iron functions as a catalytic and structural component in numerous plant processes. It is integral to chlorophyll biosynthesis and electron transport chains in photosynthesis and respiration (Kobayashi & Nishizawa, 2012). In legumes, Fe supports nodule development and nitrogenase activity, thereby enhancing biological



**Figure 1: Physiology of iron uptake in pulse crops**



ensures proper root growth, leaf greening, and reproductive success, while deficiency leads to chlorosis, impaired photosynthesis, and reduced yield.

Beyond its metabolic role, Fe contributes to plant defense and stress tolerance. Iron-dependent enzymes such as peroxidases and catalases regulate reactive oxygen species, enhancing resilience under drought and pathogen stress (Connorton et al., 2017). In nodules, Fe is critical for leghemoglobin synthesis, which maintains oxygen homeostasis for nitrogen fixation. Thus, Fe deficiency not only reduces plant vigor but also compromises symbiotic efficiency, limiting the agronomic potential of pulses.

### Soil Management Strategies

Iron availability in soils is influenced by pH, organic matter, and redox conditions. In calcareous soils, Fe deficiency is common due to insoluble Fe (III) forms. Agronomic interventions such as application of Fe chelates (EDDHA, DTPA), foliar sprays, and incorporation of organic amendments improve Fe solubility and uptake (Table 1 and Figure 2) (Lindsay, 1995). Intercropping pulses with cereals or Fe-efficient species can also enhance Fe mobilization through rhizosphere interactions.

**Table 1: Source, Recommended Dose, Chelate / Formulation of iron for pulse crops**

Source	Recommended Dose	Chelate / Formulation	Remarks
Ferrous sulfate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ )	10–20 kg Fe ha <sup>-1</sup> (soil application)	Non-chelated inorganic form	Common, economical source; effective in acidic soils; limited solubility in calcareous soils.
Fe-EDDHA (Ethylenediamine-N,N'-bis(2-hydroxyphenylacetic acid))	2–5 kg Fe ha <sup>-1</sup> (soil or fertigation)	Stable chelate	Highly effective in alkaline soils; prevents Fe precipitation; suitable for high-pH regions.
Fe-DTPA (Diethylenetriaminepentaacetic acid)	0.5–1.0 % foliar spray	Moderate stability chelate	Useful for foliar correction; less stable above pH 7; rapid greening response.



Fe-EDTA (Ethylenediaminetetraacetic acid)	0.5 % foliar spray	Standard chelate	Common in micronutrient mixtures; effective for quick correction of chlorosis.
Ferrous ammonium sulfate / Fe citrate	10–15 kg Fe ha <sup>-1</sup>	Soluble salts	Short-term correction; often combined with organic matter to improve uptake.
Organic sources (compost, manure, vermicompost)	5–10 t ha <sup>-1</sup>	Natural chelation via humic substances	Improves Fe availability through complexation; enhances microbial activity and rhizosphere Fe mobilization.
Nano-iron formulations	50–100 ppm foliar spray	Nano-chelated Fe	Emerging technology; higher efficiency and lower environmental impact; requires field validation.

Balanced fertilization is essential, as Fe interacts with phosphorus and zinc, often leading to antagonistic effects when applied excessively. Farmer extension programs that promote integrated nutrient management, soil testing, and use of Fe-efficient cultivars are crucial for sustainable adoption of Fe management practices.



**Figure 2: Soil amendment strategies for iron management**



### Molecular Breeding Approaches

Genetic variation in Fe uptake and accumulation exists among pulse genotypes, providing opportunities for breeding Fe-efficient cultivars. Iron transport is mediated by proteins such as IRT1 (Iron-Regulated Transporter 1), NRAMPs (Natural Resistance-Associated Macrophage Proteins), and YSL (Yellow Stripe-Like) transporters, which regulate uptake, translocation, and seed loading (Curie & Briat, 2003). Vacuolar sequestration and homeostasis are controlled by ferritin and transporters that prevent Fe toxicity while ensuring availability.

Functional genomics and transcriptomic studies in model legumes and cereals have identified candidate genes for Fe biofortification (Table 2). For example, overexpression of ferritin genes enhances seed Fe content, while manipulation of nicotianamine synthase improves Fe translocation (Masuda et al., 2009). Marker-assisted selection and QTL mapping can be employed to identify Fe-efficient genotypes, while biotechnological approaches such as transgenic expression of Fe transporters offer long-term solutions for biofortified pulses. Molecular strategies to enhance iron nutrition in pulse crops focus on improving uptake, translocation, storage, and seed biofortification. Key transporters such as *IRT1*, *NRAMPs*, and *FRO2* regulate Fe<sup>2+</sup> absorption from the rhizosphere, while nicotianamine synthase (*NAS*) and yellow stripe-like (*YSL*) transporters facilitate chelation and long-distance movement of Fe within the plant (Curie & Briat, 2003; Kobayashi & Nishizawa, 2012). Vacuolar sequestration and seed storage are mediated by ferritin and vacuolar iron transporter (*VITI*), ensuring both homeostasis and nutritional enrichment (Guerinot & Yi, 1994; Connorton et al., 2017). Advances in transcriptomics and functional genomics have identified Fe-responsive genes and regulatory networks, including *FIT* and bHLH transcription factors, which coordinate iron homeostasis under deficiency stress (Masuda et al., 2009). Marker-assisted selection and QTL mapping further enable the identification of Fe-efficient genotypes in chickpea, lentil, and mung bean, while biotechnological approaches such as transgenic ferritin expression and CRISPR-based editing offer promising avenues for biofortification. Collectively, these molecular tools provide a robust framework for developing Fe-efficient pulse varieties that address both agronomic performance and human nutritional security.

**Table 2: Iron uptake enhancement and key genes/pathways in pulses**

Approach / Mechanism	Key Genes / Pathways	Description / Strategy	Representative Sources



Iron Uptake Enhancement	<i>IRT1</i> , <i>NRAMP1</i> , <i>FRO2</i>	Overexpression of iron-regulated transporter ( <i>IRT1</i> ) and ferric reductase oxidase ( <i>FRO2</i> ) genes to improve Fe <sup>2+</sup> uptake from rhizosphere.	Kobayashi & Nishizawa, 2012; Curie & Briat, 2003
Chelation and Translocation	<i>NAS</i> , <i>NAAT</i> , <i>YSL1-3</i>	Manipulation of nicotianamine synthase ( <i>NAS</i> ) and yellow stripe-like ( <i>YSL</i> ) transporters to enhance Fe chelation and long-distance transport.	Masuda et al., 2009; Connorton et al., 2017
Vacuolar Sequestration and Storage	<i>Ferritin</i> , <i>VIT1</i> , <i>NRAMP3/4</i>	Expression of ferritin and vacuolar iron transporter genes to increase seed Fe storage and prevent toxicity.	Guerinot & Yi, 1994; Kobayashi & Nishizawa, 2012
Rhizosphere Mobilization	<i>Siderophore biosynthesis genes</i>	Engineering rhizobial or plant siderophore pathways to improve Fe solubilization and uptake efficiency.	Marschner, 2012; Lindsay, 1995
Regulation of Iron Homeostasis	<i>FIT</i> , <i>bHLH38/39</i> , <i>FER-like transcription factors</i>	Transcriptional regulation of Fe uptake and transport genes under deficiency conditions.	Curie & Briat, 2003; Kobayashi & Nishizawa, 2012
Biofortification via Genetic Engineering	<i>Ferritin</i> , <i>NAS</i> , <i>YSL</i> , <i>VIT1</i>	Transgenic or CRISPR-based enhancement of Fe accumulation in seeds for improved human nutrition.	Masuda et al., 2009; Connorton et al., 2017
Marker-Assisted Selection (MAS)	Fe-efficiency QTLs in chickpea, lentil, mung bean	Identification and introgression of Fe-efficient alleles through QTL mapping and MAS.	Singh et al., 2016; Sharma et al., 2017



Transcriptomic and Functional Genomics	Fe-responsive transcriptome profiling	RNA-seq and microarray studies to identify Fe-responsive genes and signaling networks in legumes.	Pandey et al., 2020; Connorton et al., 2017
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### Extension Strategies

Farmer awareness programs are essential for disseminating knowledge on Fe nutrition. Nutrient management packages that integrate Fe fertilization with improved cultivars can significantly enhance productivity and seed quality. Policy support is needed to incorporate Fe into pulse nutrient guidelines, linking agricultural innovation with public health outcomes. Biofortified Fe-rich pulses can help combat iron deficiency anemia, particularly in vegetarian populations across South Asia and Africa.

### Conclusion

Iron nutrition is fundamental to pulse crop productivity and seed quality. Agronomic interventions such as Fe chelates, foliar sprays, and balanced fertilization can mitigate deficiencies, while molecular breeding offers pathways to biofortification. Integrating soil management, plant physiology, and genomics will enable the development of Fe-efficient pulse varieties that address both agricultural and nutritional challenges. Future research should focus on rhizosphere interactions, transporter regulation, and farmer-centric extension to ensure sustainable adoption.

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