



# Nanoparticles as Nano-Fertilisers: A Sustainable Approach to Enhancing Crop Productivity

Arun Gutte<sup>1</sup> and Sandesh Jaybhaye<sup>2</sup>

<sup>1</sup>Extention Agronomist, College of Agriculture, Ambajogai

<sup>2</sup>Department of Chemistry, B.K. Birla College (Empowered Autonomous Status), Kalyan

## Abstract

The rapid growth of global population and the consequent demand for food have intensified the need for sustainable agricultural practices. Conventional chemical fertilizers, although effective in increasing crop yield, are associated with low nutrient use efficiency, soil degradation, and adverse environmental impacts. Nanotechnology offers promising solutions to these challenges through the development of nano-fertilizers with enhanced efficiency and reduced ecological footprint. Among various nanomaterials, ferrite nanoparticles ( $MFe_2O_4$ ; M = Zn, Cu, Ni, Co, Mg, etc.) have gained significant attention due to their magnetic properties, controlled nutrient release, biocompatibility, and multifunctionality. Green synthesis of ferrite nanoparticles using plant extracts provides an eco-friendly, cost-effective, and sustainable alternative to conventional physical and chemical synthesis routes. This review comprehensively discusses green synthesis methods of ferrite nanoparticles using different plant parts, their advantages and limitations, and their application as nano-fertilizers. The role of ferrite nanoparticles in improving crop growth, yield, nutrient uptake, and environmental sustainability is critically analyzed. The review highlights their effects on crop quality and quantity, yield enhancement, and environmental impact, emphasizing their potential as next-generation fertilizers for sustainable agriculture.

**Keywords:** Green synthesis; Ferrite nanoparticles; Nano-fertilizers; Sustainable agriculture; Crop productivity

## 1. Introduction

Agriculture plays a vital role in ensuring food security and economic stability, particularly in developing countries. However, excessive use of conventional fertilizers has resulted in nutrient leaching, soil infertility, groundwater contamination, and greenhouse gas emissions [1]. Therefore, there is an urgent need to develop innovative and sustainable fertilization strategies that enhance nutrient use efficiency while minimizing environmental damage.

Nanotechnology has emerged as a transformative tool in agriculture, enabling precise nutrient delivery and controlled release mechanisms [2]. Nano-fertilizers improve nutrient availability, reduce losses, and enhance plant growth at lower application rates compared to bulk fertilizers [3]. Ferrite nanoparticles, a class of spinel metal oxides, are particularly attractive due to their stability, magnetic behavior, and ability to supply essential micronutrients such as iron, zinc, and magnesium [4].

Green synthesis of ferrite nanoparticles using plant extracts aligns with the principles of green chemistry by avoiding toxic chemicals, reducing energy consumption, and utilizing renewable biological resources [5]. This review focuses on green-synthesized ferrite nanoparticles and their emerging role as nano-fertilizers in sustainable agriculture.

## 2. Materials and Methods: Green Synthesis of Ferrite Nanoparticles

### 2.1 Green Synthesis Approach

Green synthesis involves the use of biological entities such as plant extracts, bacteria, fungi, and algae as reducing, stabilizing, and capping agents [6]. Among these, plant-mediated synthesis is widely preferred due to simplicity, scalability, and availability of phytochemicals such as flavonoids, phenolics, terpenoids, and alkaloids.

In a typical synthesis, aqueous plant extract is mixed with metal salt precursors (e.g.,  $\text{FeCl}_3$ ,  $\text{FeSO}_4$ ,  $\text{Zn}(\text{NO}_3)_2$ ). The phytochemicals reduce metal ions and facilitate the formation of ferrite nanoparticles, followed by calcination to improve crystallinity [7].

### 2.2 Plant Parts Used in Green Synthesis

Different plant parts are employed depending on their phytochemical composition.

**Table 1. Plant parts used for green synthesis of ferrite nanoparticles**

Plant part	Examples of plants	Role in synthesis
Leaves	Neem, Tulsi, Tea	Rich in polyphenols; strong reducing agents
Roots	Ginger, Turmeric	Act as stabilizing and capping agents
Fruits	Lemon, Orange peel	Organic acids aid nucleation
Seeds	Fenugreek, Mustard	Proteins and amino acids control particle size
Bark	Cinnamon	Enhances crystallinity and stability

### 2.3 Advantages and Disadvantages of Green Synthesis

#### Advantages

- Eco-friendly and non-toxic process [8]
- Cost-effective and energy efficient
- Biocompatible nanoparticles suitable for agriculture
- Reduced environmental and health hazards

#### Disadvantages

- Limited control over particle size and morphology
- Batch-to-batch variation due to plant extract composition
- Scale-up challenges for industrial production

## 3. Ferrite Nanoparticles as Nano-Fertilizers: Results and Discussion

### 3.1 Crops Studied

Ferrite nanoparticles have been tested on various crops such as wheat, rice, maize, tomato, soybean, spinach, and mustard [9–11].

### 3.2 Benefits and Application Methods

Ferrite nano-fertilizers supply essential micronutrients, particularly iron and zinc, which are crucial for chlorophyll synthesis, enzyme activation, and photosynthesis.

#### Application methods include:

- Seed priming
- Soil application
- Foliar spray

Lower doses (10–100 mg/L) are generally effective, reducing fertilizer consumption [12].

### 3.3 Impact on Crop Quality and Quantity

Studies have shown that ferrite nanoparticles enhance seed germination, root and shoot length, biomass accumulation, and chlorophyll content [13]. Improved nutrient uptake leads to better grain quality, protein content, and micronutrient enrichment.

### 3.4 Crop Yield Enhancement

Yield improvements ranging from 10–30% have been reported in cereals and vegetables due to improved nutrient efficiency and stress tolerance [14].

### 3.5 Environmental Impact

Green ferrite nano-fertilizers reduce nutrient leaching, minimize soil contamination, and lower greenhouse gas emissions compared to conventional fertilizers [15]. Their magnetic nature also allows potential recovery from soil, reducing long-term accumulation risks.

### 3.6 Advantages and Disadvantages as Nano-Fertilizers

#### Advantages

- Controlled and targeted nutrient release
- Enhanced nutrient use efficiency
- Reduced fertilizer dosage
- Eco-friendly and sustainable

#### Disadvantages

- Long-term toxicity and accumulation need evaluation
- Regulatory and safety concerns
- Higher initial research and development cost

### 4. Conclusion

Green-synthesized ferrite nanoparticles represent a promising class of nano-fertilizers for sustainable agriculture. Their eco-friendly synthesis, multifunctional properties, and ability to enhance crop productivity while minimizing environmental impact make them suitable alternatives to conventional fertilizers. However, comprehensive field trials, long-term environmental risk assessment, and regulatory frameworks are essential before large-scale agricultural adoption. With continued research and interdisciplinary collaboration, green ferrite nano-fertilizers can significantly contribute to future food security and sustainable farming practices.

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