IRON FORTIFICATION OF HERBS TO INCREASE NUTRITIVE VALUE

Vaishnavi P[1], Prastuthi Elish[2], Prakruthi, Mubeena[3], Dr Shilpa Sivashankar[4]

Department of Biotechnology, Acharya Institute of Technology Affiliated to Visvesvaraya Technological University, Belagavi, Recognized by AICTE and Accredited by NBA, New Delhi

Abstract: Aims: To enhance nutritive value of herbs to address health conditions. Anemia is a lot more concerning as 50% women are suffering from this. Anemia is always tackled by considering factors like iron content, vitamins, and mineral richness. We have enhanced the nutritive value of herbs by iron fortification through nano particles.

Study Design: Iron deficiency anemia, as defined by the World Health Organization (WHO), is characterized by a hemoglobin (Hb) level below 13 g/dl in men and 12 g/dl in women. In recent times, approximately one-third of the global population has been affected by iron deficiency. Herbs like coriander and Methi are most used in Indian diets and are easy to grow too. Hence, increasing iron content in these commonly used herbs by applying nanoparticles through food could improve the iron intake through diet thus, preventing people from being susceptible to iron deficiency disorders. Iron Nanoparticles could be easily synthesized by various plants that are iron eg: Papaya, Hibiscus etc. These iron nanoparticles can be synthesized from different sources. This paper mainly involves studying various sources from which nanoparticles can be synthesized and selection of the source as well as the method that is most suitable to synthesize the nanoparticles.

Conclusion : The nanoparticles were successfully extracted, and their characteristics were analyzed using FTIR. To study the impact of these nanoparticles on plant growth, different pots were prepared: one with no additives as a control, another with chemical fertilizer, and a third with the nanoparticles. Notably, the herbs, particularly fenugreek (Methi), exhibited rapid growth within just 12 days when treated with the chemical fertilizer. However, their leaves started drying up and deteriorating by the 15th day, indicating that the chemical fertilizer disrupted the plants' metabolism. In contrast, coriander herbs showed slow but healthy growth when treated with the chemical fertilizer. On the other hand, both fenugreek and coriander seeds sown with nanoparticles displayed robust and healthy growth without any adverse effects.

Keywords: Anemia, nutrition, fertilizer, nanoparticle, fortification

Methodology:

Sl.no	Method	Nano-particle synthesized	Applications
1	Green synthesis of iron oxide nanoparticle using *Carica papaya* leaf extract	Iron oxide nanoparticle	Photocatalytic degradation of remazol yellow RR dye and antibacterial activity
2	Chemical Reduction with Palladium Ion Seeds	Iron Nanoparticles	Biomedical applications Environmental Remediation
3	Biogenic synthesis of magnetic iron oxide	Magnetic iron oxide	Characterization, antimicrobial, antioxidant activity and *in*

	nanoparticles using inedible borassus flabellifer seed coat		*vitro* cytotoxicity analysis
4	Green synthesis of Iron nanoparticles using aqueous extract of Musa ornate flower sheath	Iron nanoparticles	Antibacterial activity
5	Microbial synthesis of iron-based nanomaterials	Synthesis of metal nanoparticles, with an emphasis on iron oxide nanoparticles	Industries, including technology and medicine.
6	Biocatalysis as a Green Approach for Synthesis of Iron Nanoparticles	Iron Nanoparticles	Control, efficiency, and scalability of microfluidic systems
7	One-pot green synthesis of iron oxide nanoparticles from *Bauhinia tomentosa*	Iron oxide nanoparticles	Characterization techniques to clarify the particles' structural, morphological, and magnetic features
8	Plant-Mediated Green Synthesis of Iron Nanoparticles	Iron Nanoparticles	Reducing and stabilizing agents
9	Biomimetic synthesis of iron oxide nanoparticles from *Bacillus megaterium*	Iron oxide nanoparticles	Hyperthermia therapy
10	Synthesis of Iron Oxide Nanoparticles Using Isobutanol	Iron Oxide Nanoparticles	Biomedical applications

1. INTRODUCTION

Iron deficiency anemia is one of the most prevalent illnesses or disorders associated with iron deficiency. Over 2 billion people worldwide are impacted by this common nutritional problem, which accounts for roughly half of all occurrences of anemia. Human functioning is affected by iron shortage at even mild and moderate levels, which are below the threshold for iron deficiency anemia (IDA). Menstrual loss, unusual uterine bleeding, and pregnancy are among the conditions that might cause iron deficiency in women. Infants' cognitive performance, behavior, and physical growth are negatively impacted by them.[1] According to the World Health Organization (WHO), hemoglobin (Hb) levels below 12 g/dl for women and 13 g/dl for males are indicative of iron deficiency anemia. In recent years, iron deficiency has afflicted about one-third of the world's population. Infants, the elderly, and women, particularly during menstruation and pregnancy, are at increased risk for iron deficiency anemia (IDA) [2]. Debilitating weariness, a decreased capacity for activity, and poor work performance can all result from this illness. Additionally, it has been demonstrated that iron shortage and anemia during pregnancy have harmful effects on both the mother and the baby, including neuropsychological deficits in the offspring of iron-deficient mothers [3]. Anemia was present in 23.2% (95% CI 22.7-23.7) of men, with 5.1% (4.9-5.4) experiencing moderate to severe anemia and 0.5% (0.5-0.6) experiencing severe anemia [4]. To tackle severe IDA, most people should make dietary changes as well as consume iron supplements, iron tablets, vitamin C, folic acid, and/or oligosaccharides supplements. Typical daily diets do not generally involve iron-rich foods and hence most people do not get their daily dose of iron. Incorporating iron-rich foods in our diet beforehand could help avoid iron deficiency problems and eventually prevent the intake of such supplements [5].

The provision of daily iron supplementation has the potential to raise hemoglobin (Hb) levels and lower the risk of anemia and iron deficiency anemia (IDA) in infants, preschoolers, and school-aged children, as well as pregnant and non-pregnant women [6]. However, the utilization of iron supplementation has the potential to lead to undesirable gastrointestinal consequences, including abdominal discomfort, constipation, or feelings of nausea [7]. Therefore, to overcome such nutritional deficiencies, one must stick to plant-based sources.

One of the major reasons for iron deficiency in plants is to lack of availability of iron in soluble form in the soil, the form of iron that would easily be taken by plants. Fe deficiency is one of the major problems of calcareous soils, which account for one-third of the cultivated areas in the world. Although Fe is the fourth most abundant element in the lithosphere (5% of the earth's crust), the amount of plant-available Fe in the soil may vary depending on the soil material and environmental factors, such as soil pH, the redox potential of soil, the presence of carbonates/bicarbonates in the environment, and high concentrations of phosphorous. Iron deficiency is usually observed in alkaline or over-limed soils because, at high pH, Fe is oxidized into insoluble ferric (Fe^{3+}) forms, predominately ferric oxides. The amount of soluble Fe reaches the minimum level at pH 6.5–8.0. At lower pH, Fe becomes more available for plant uptake. Additionally, the presence of pollutants, such as Cadmium Cd^{2+} and Cobalt Co^{2+}, in the soil has also been shown to interfere with Fe uptake by preventing the transport of Fe from roots to shoots [8]. In different food items, iron is available in two forms, heme, and non-heme iron. Heme iron, which makes up 40% of the iron of non-vegetarian diets such as meat, poultry, and fish, is well absorbed. Non-heme iron constitutes 60% of the iron in animal tissues, and all the iron in plants (fruits, vegetables, grains, nuts, etc.) is not absorbed properly. Vegetarian people require 1.8 times more iron than non-vegetarian people as they have to depend on a non-heme iron diet to fulfill iron demand; therefore, the selection of an iron-rich diet and better bioavailability techniques are crucial to meet the demand.

To address iron deficiency, it is crucial to identify and promote existing iron-rich green leafy vegetables (GLVs) based on their iron availability. Among these, commonly cultivated leafy vegetables in India include Amaranthus (25.50 mg/100 g), fenugreek leaves (16.50 mg/100 g), palak (16.20 mg/100 g), spinach (15.50 mg/100 g), and basella (10.50 mg/100 g). Enriching common green leafy vegetables (GLVs) with iron can enhance the overall iron content and bioavailability in daily diets, thereby assisting in the reduction of the growing global issue of iron deficiency anemia However, biofortified GLVs would be more readily accepted if the fortified leaves had a higher density of iron compared to other varieties [9]. The Indian diet makes extensive use of a wide range of seasonal, green, leafy vegetables, including mustard leaves, amaranth, fenugreek, and spinach. They add fiber, vitamins, antioxidants, iron, and calcium without raising the calorie or carbohydrate intake. Hence, increasing iron content in these herbs is the most feasible way to increase iron consumption [10]. Fertilizers and pesticides are essential for modern agriculture, as they provide crops with the necessary nutrients and protect them from disease and pests. However, the increasing use of these chemicals has raised concern about their impact on human health. Over the past few decades, using fertilizers and pesticides has increased exposure to these chemicals for farmers, farm workers, and the general population. It has raised serious questions about the potential risks of these chemicals and their impact on human health [11]. Overuse of chemical fertilizers and agrochemicals can weaken soil structure, raise salinization and acidity, and lower production and nutrient levels. Additionally, it can reduce soil enzyme activity and upset the biotic life in the soil [12]. There are various possible benefits associated with the use of NMs in environmentally friendly agrochemicals. NMs can improve the biopesticides' stability, dispersibility, and efficacy, which will improve their performance in controlling pests. NMs can release bioactive compounds under control, which can extend their action and decrease the frequency of application. Furthermore, using NMs can prevent biopesticides from degrading and transport them precisely to target pests or plant sections, reducing off-target effects and maximizing efficacy [13]. There are different modes of iron intake. Iron supplementation is the most popular method for managing the global issue of anemia and iron deficiency. An essential part of the body is iron. Its main function is to store and move iron (in the form of hemoglobin and myoglobin) throughout the body. Because small erythrocytes form in an iron-deficient state,

hemoglobin cannot be produced, leading to microcytic anemia.The purpose of iron supplementation is to replenish those iron reserves and promote oxygen delivery and erythropoiesis throughout the body. The divalent metal transporter 1 (DMT1) carries iron across the cell membrane to the macrophage, where it is integrated and stored as ferritin. The body subsequently transforms this form into an absorbable Fe2+ ion, which transferrin then sequesters to different locations, such as the bone marrow for the formation of red blood cells [14]. Up to 60% of people taking oral iron supplements report gastrointestinal side effects. These GI complaints cause up to 50% of oral iron-receiving patients to not follow the treatment plan, meaning their IDA persists [15]. Excess iron may be detrimental to cognitive, motor, and behavioural development, although this detrimental effect is likely limited to cases of genetically susceptible children [16]. Another method of iron intake is through diet. Dietary iron can be divided into two categories: heme iron, which is derived from haemoglobin, and myoglobin in foods derived from animals, and nonheme iron, which is found in both plant and animal tissues. In meat-eating communities, heme iron is expected to contribute 10–15% of total iron intake; but, due to its more uniform and higher absorption (estimated at 15–35%), it may contribute up to 40% of total absorbed iron.
Phytate, also known as Myo-inositol hexakisphosphate, is the primary iron absorption barrier in plant-based diets. It has been demonstrated that the detrimental effects of phytate on iron absorption are dose-dependent and begin at incredibly low values of 2–10 mg/meal. Plant-based meals and drinks, including fruit, vegetables, some cereals and legumes, tea, coffee, and wine, contain different quantities of polyphenols. It has been demonstrated that polyphenols in herbs and black teas limit the absorption of iron [17]. The field of biotechnology and agricultural industries can benefit greatly from the use of nanotechnology, as nanoparticles possess unique physicochemical properties such as high surface area, reactivity, tuneable pore size, and particle morphology. These nanoparticles can be utilized as targeted carriers for herbicides, nano-pesticide fertilizers, or genes, enabling them to deliver their contents to specific cellular organelles in plants. While there is some information available on the toxicity of nanoparticles to plants, few studies have explored the mechanisms through which nanoparticles affect plant growth and development. Therefore, this review focuses on the significant role of nanoparticles in plants and how nanoscience provides insights into their mode of action. By understanding the physiological, biochemical, and molecular mechanisms of nanoparticles in plants, we can enhance plant growth and development [18].

This paper outlines various methods and sources for synthesizing iron nanoparticles to enhance iron content in plants.

2. MATERIALS AND METHODS

2.1 GREEN SYNTHESIS OF IRON OXIDE NANOPARTICLE USING *Carica papaya* LEAF EXTRACT: APPLICATION FOR PHOTOCATALYTIC DEGRADATION OF REMAZOL YELLOW RR DYE AND ANTIBACTERIAL ACTIVITY

The environmentally benign and non-toxic characteristics of the recently proposed technology for producing iron oxide nanoparticles using papaya leaf extract has shown significant potential. Using hexahydrate ferric chloride ($FeCl_3 \cdot 6H_2O$) and papaya leaf extract, alpha-phase iron oxide nanoparticles (α-Fe_2O_3) were successfully produced in this study under ambient air circumstances. The effective production of the iron oxide nanoparticles was verified by several characterization methods, including FTIR, XRD, FESEM, EDX, and TGA. Higher concentrations of iron oxide nanoparticles caused the dye to decolorize further, and after 6 hours and 0.8 g/L of catalyst, the highest degradation rate of 76.6% was reached at pH 2. At a dye concentration of 70 ppm and a catalyst dosage of 0.4 g/L, the photocatalyst's unit removal capability was found to be 340 mg/g. Furthermore, the produced nanoparticles demonstrated a modest level of antibacterial activity against strains of bacteria, including S. aureus, E. coli, Pseudomonas spp., and Klebsiella spp. The nanoparticles showed potential for causing harm to tumor cells, especially to Hela and BHK-21 cell lines, even though they were cytotoxic to Vero, BHK-21, and Hela cell lines at high concentrations [19].

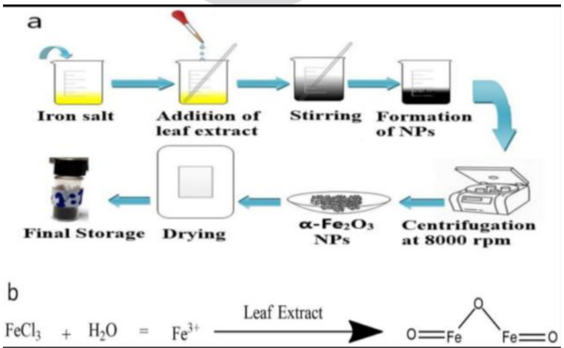

Fig 1: Synthesis of Iron Nanoparticle [3].

2.2 SYNTHESIS OF IRON NANOPARTICLES VIA CHEMICAL REDUCTION WITH PALLADIUM ION SEEDS

This work used sodium borohydride as the reducing agent and ferric chloride as a precursor to successfully synthesize iron nanoparticles with an average diameter of 6 nm and a geometric standard deviation of 1.3 at a pH of 9.50. To prevent nanoparticle aggregation and promote uniform dispersion, polyacrylic acid (PAA) was used as a dispersing agent. By encouraging heterogeneous nucleation onto palladium clusters, the inclusion of palladium ions as seeds further decreased the nanoparticle diameter. At 5 K and 350 K, respectively, this technique produced ferromagnetic and superparamagnetic nanoparticles. Notably, only aggregated nanoparticles were produced when PAA was absent, emphasizing the dispersing agent's crucial involvement in the synthesis of nanoparticles. The pH of the solution also had a big impact on the size of the nanoparticles by changing the conformation of the polymer chain and ionizing PAA. Because of decreased palladium seed availability and decreased PAA ionization, lower pH produced bigger nanoparticles (59 nm in diameter). This thorough comprehension of the synthesis factors allows for exact control over the properties of iron nanoparticles, increasing their potential in a range of technological applications [20].

2.3 biogenic synthesis of magnetic iron oxide nanoparticles using inedible borassus flabellifer seed coat: characterization, antimicrobial, antioxidant activity and *in vitro* cytotoxicity analysis

Borassus flabellifer is easy to cultivate and has a rich phytochemical content, it presents a prospective source for nanoparticle synthesis. Borassus flabellifer is widely available in Southeast Asia and Asia. Highlighting the promise of plant-mediated synthesis for a range of applications, many metal nanoparticles produced utilizing plant extracts are presented. The extract from Borassus flabellifer seed coverings is extracted and used as a capping and reducing agent during the manufacture of nanoparticles. Ferric chloride and ferrous sulfate precursor solutions are made, and synthesis is carried out under carefully monitored circumstances. To examine the produced nanoparticles, characterization techniques such as FTIR, UV-Vis spectroscopy, XRD, SEM, and EDAX are used. The agar well diffusion method is used to evaluate antimicrobial activity, and hemolytic activity tests and the MTT assay are used to evaluate cytocompatibility. Assays for hydroxyl radical scavenging, hydrogen peroxide, and DPPH are used to measure antioxidant activity. The produced nanoparticles have magnetic characteristics and are mostly made of magnetite phase, with trace amounts of hematite. Nanoparticle production is confirmed by UV-Vis spectra, and surface functionalization with phytochemicals is suggested by FTIR studies. SEM pictures show smooth-surfaced, hexagon-shaped nanoparticles. Antimicrobial experiments show considerable efficacy against fungi and bacteria, suggesting possible uses in biomedicine and bioremediation. High fibroblast cell survival in the presence of nanoparticles is revealed by cytocompatibility testing, which is crucial for biomedical applications. The nanoparticles also show significant antioxidant activity, which raises the possibility of their therapeutic application.

The work shows how Borassus flabellifer seed coat extract may be used to create magnetic iron oxide nanoparticles that are antioxidant, cytocompatible, and antibacterial in a green way. The nanoparticles' potential for a range of environmental and biological uses emphasizes the significance of green synthesis techniques in nanotechnology [21].

2.4 green synthesis of iron nanoparticles using aqueous extract of musa ornate flower sheath against pathogenic bacteria

Nanotechnology, with its versatile applications across biology, medicine, and engineering, represents a rapidly advancing field. While efficient, conventional nanoparticle manufacturing techniques are frequently expensive and detrimental to the environment. Green synthesis techniques that make use of natural resources like plant extracts are being investigated by researchers in response. This review highlights the possible antibacterial characteristics of Musa ornata flower sheath extract in the green manufacture of iron nanoparticles, or FeNPs.
The work describes a methodical procedure for creating FeNPs, which includes making aqueous $FeSO_4$ solutions and adding M. ornata flower sheath extract to them. A range of parameters, including pH, reaction time, and precursor salt content, were studied to maximize the synthesis of nanoparticles. The produced FeNPs were evaluated using characterization techniques such as zeta potential analysis, XRD, FTIR, AFM, and UV/Vis spectrophotometry. Using the good diffusion method, antimicrobial activity against common infections was assessed.
Using M. ornata flower sheath extract, the study successfully illustrates the green synthesis of FeNPs, offering a practical and sustainable substitute for conventional techniques. The study validates the production and stability of

FeNPs with potential uses in antimicrobial therapy by thorough characterization. To fully realize the therapeutic potential of these nanoparticles, more investigation into other biological functions and adjustment of the production parameters are necessary. In general, the research adds to the expanding corpus of information regarding green nanotechnology and its consequences for environmentally friendly biological uses [22].

2.5 microbial synthesis of iron-based nanomaterials

The study explores the use and synthesis of metal nanoparticles, with an emphasis on iron oxide nanoparticles, which are essential for several industrial applications, including environmental remediation and the biomedical industries. It clarifies the basic ideas of nanotechnology while highlighting the special qualities of nanoparticles and their capacity to completely transform a range of industries. The study emphasizes how crucial it is to comprehend how metal nanoparticles' size, shape, composition, and crystallinity affect their physical and chemical characteristics.

The manufacture of iron oxide nanoparticles is described in detail in this work, with a comparison of chemical and physical processes. Classifying the synthesis methods according to how environmentally friendly they are, highlights the need for exact control over the size, distribution, shape, and stability of the particles. A thorough explanation is provided of the biological creation of iron oxide nanoparticles, namely through biomineralization mechanisms. The importance of microorganisms in the creation of nanoparticles is highlighted as the publication outlines the mechanisms underpinning biologically induced biomineralization (BIM) and biologically regulated biomineralization (BCM). Thorough accounts of biosynthesis via sulfate-reducing bacteria (SRB) and Fe(III)--reducing bacteria (FRB) are given, clarifying the biochemical processes involved in the creation of magnetite. The study also discusses biosynthesis using magnetotactic bacteria (MTB), clarifying the genetic regulation of magnetosome development and its consequences on the shape and magnetic properties of nanoparticles.

The research paper concludes by highlighting the importance and wide range of uses of iron oxide nanoparticles in a variety of industries, including technology and medicine. It draws attention to the possibility that biologically mediated synthesis techniques could provide effective and sustainable ways to produce nanoparticles. To facilitate the integration of these biosynthetic processes into practical applications, the report highlights the necessity of additional research aimed at optimizing and scaling up these approaches. All things considered, the work offers insightful information about the characteristics and methods of synthesis of iron oxide nanoparticles, opening new avenues for the development of nanotechnology and its many uses [23].

2.6 biocatalysis as a green approach for synthesis of iron nanoparticles—batch and microflow process comparison

This study paper presents a thorough description of the environmentally friendly production of iron nanoparticles using plants, algae, bacteria, and fungi. The text examines the diverse mechanisms that are implicated in the manufacturing process, encompassing both extracellular and intracellular pathways. It underscores the significance of bioactive molecules found in these biological materials as agents that reduce and cap. The benefits of green synthesis techniques over conventional chemical synthesis are also discussed in the study, with a focus on how environmentally friendly and potentially highly productive they are.

The methods for creating iron nanoparticles utilizing a variety of biological materials—including bacteria, fungi, algae, and plants—are described in the publication. It describes the procedures for each approach, including the creation of precursor solutions, the extraction of bioactive substances, and the adjustment of reaction parameters including pH, temperature, and incubation duration. The synthesis methods are explained, including how reaction parameters affect particle size, shape, and yield, and how bioactive chemicals function as reducing agents to transform iron ions into nanoparticles. The study also covers characterization methods including UV spectroscopy, FTIR, SEM, TEM, and DLS that are used to verify the creation of nanoparticles. It also emphasizes how crucial process optimization is and how different parameters like extract concentration, precursor ratio, and reaction temperature affect the final product's quality when it comes to manufactured nanoparticles.

To sum up, the study offers insightful information about the environmentally friendly synthesis of iron nanoparticles from biological resources. It illustrates the viability and efficiency of employing plants, algae, bacteria, and fungi as environmentally benign substitutes for chemical processes in the manufacture of nanoparticles. The significance of comprehending synthesis mechanisms and refining reaction conditions to attain targeted nanoparticle characteristics is emphasized in the work. Furthermore, it highlights the advantages in terms of control, efficiency, and scalability of microfluidic systems, emphasizing their potential for continuous nanoparticle manufacturing. All things considered, the work adds to the expanding corpus of information on green nanotechnology and offers insightful advice for the next studies in the area [24].

2.7 one-pot green synthesis of iron oxide nanoparticles from *bauhinia tomentosa*: characterization and application towards synthesis of 1, 3 diolein

The study explores the production of iron oxide nanoparticles from Bauhinia tomentosa leaf extract and their use in the enzymatic manufacture of 1,3 diolein. The introduction highlights the benefits of green synthesis techniques over traditional chemical methods and gives a thorough review of the growing significance of nanoscience and technology across a range of sectors. It draws attention to the importance of magnetic nanoparticles as well as the potential uses of iron oxide nanoparticles in a variety of industries, including biomedicine and catalysis. In addition, it provides background information for the current research by going over earlier investigations into the manufacture of iron oxide nanoparticles utilizing various plant extracts and their uses.

The materials and procedures used to immobilize porcine pancreatic lipase (PPL) and synthesize iron oxide nanoparticles, which were then used to enzymatically synthesize 1,3 diolein, are described in detail in the study. It explains how Bauhinia tomentosa leaf extract and $FeCl_3$ solution are used to biosynthesize nanoparticles. Next, characterization methods like UV-Vis spectrometry, FTIR (Fourier transform infrared spectroscopy), thermogravimetry and differential scanning calorimeter (TGA-DSC), X-ray diffraction (XRD), surface area analysis of Brunauer–Emmett–Teller (BET) surface area analysis, analysis using vibrating sample magnetometer (VSM) and zeta potential analysis are employed to describe the process. Comprehensive explanations of the 1,3 diolein synthesis and lipase immobilization processes are also provided, together with information on the reaction conditions and analytical methods used for characterization.

The generated iron oxide nanoparticles are thoroughly analyzed in the results and discussion section, which also uses a variety of characterization techniques to clarify the particles' structural, morphological, and magnetic features. The successful synthesis and characterization of nanoparticles is confirmed by the provision of comprehensive spectroscopic and microscopic data accompanied by graphical representations. Additionally, the effectiveness of PPL immobilization on iron oxide nanoparticles and its catalytic activity in the manufacture of 1,3 diolein is assessed in this section. A thorough investigation of the impact of reaction parameters on diolein yield highlights the significance of temperature, substrate molar ratio, and enzyme reusability [25].

2.8 plant-mediated green synthesis of iron nanoparticles

This study investigates the production of iron nanoparticles by employing plant extracts as stabilizing and reducing agents. It emphasizes how crucial green synthesis techniques are for creating nanoparticles and how using plant resources is both economical and environmentally beneficial. The article addresses the several plant species—such as tea, eucalyptus, sorghum, and others—that are used in the synthesis of nanoparticles as well as the techniques used, like hydrothermal and room temperature synthesis. Additionally, it explores the possible uses of these nanoparticles, specifically in water and environmental cleanup.

The synthesis of iron nanoparticles using plant extracts involved several steps, including the preparation of plant extracts, mixing them with metal salt solutions, and allowing the reaction to occur either at room temperature or through hydrothermal methods. Various plant species were investigated for their efficacy in nanoparticle synthesis, with parameters such as extract concentration, reaction time, and temperature being optimized to control the size and morphology of the nanoparticles. Characterization techniques such as XRD, FTIR, TEM, and SEM were employed to analyze the structure, composition, and morphology of the synthesized nanoparticles. Additionally, the catalytic and adsorption properties of the nanoparticles were evaluated for their potential applications in pollutant degradation and removal.

The research study highlights the usefulness of plant extracts as reducing and stabilizing agents while offering insightful information on the environmentally friendly synthesis of iron nanoparticles. The study shows the wide variety of plant resources that can be used to synthesize nanoparticles, providing a sustainable and greener substitute for traditional chemical approaches. The promising catalytic and adsorption capabilities of the produced nanoparticles make them attractive candidates for a range of applications, such as environmental remediation, wastewater treatment, and water purification. All things considered, the study adds to the expanding field of green nanotechnology and emphasizes how crucial it is to use natural resources in the synthesis of sustainable nanomaterials[26].

2.9 biomimetic synthesis of iron oxide nanoparticles from *bacillus megaterium* to be used in hyperthermia therapy

The study discusses the increasing interest in the synthesis and manufacturing of magnetic nanoparticles, especially iron oxide nanoparticles, because of their numerous uses in diverse disciplines. It highlights how crucial it is to choose the right synthesis pathways to obtain desirable qualities including stability, size, shape, and surface features. Citing

instances of green synthesis from sources like bacteria, fungi, and plants, the study emphasizes the benefits of biological and nature-inspired techniques over conventional physicochemical procedures. It provides context for the study's main objective, which is to create biological nanocarriers with desired magnetic characteristics for therapeutic uses by synthesizing iron oxide nanoparticles using Bacillus megaterium.
The ingredients and experimental techniques utilized to create the iron nanoparticles are thoroughly described in the publication. It describes the bacterial strain and culture medium that was used, as well as how Bacillus megaterium was used to synthesize the nanoparticles. To thoroughly characterize the synthesized nanoparticles, a range of analytical methods are used, including zeta potential measurement, Raman spectroscopy, X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDS), dynamic light scattering (DLS), X-ray spectrophotometry, field-emission scanning electron microscopy (FESEM), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR).
The results from every analytical method used in the investigation are shown in the results section. The observations include color changes that indicate the synthesis of nanoparticles, UV-visible spectra that confirm the formation of nanoparticles, FESEM images that reveal the morphology and size of the particles, EDS analysis that confirms the elemental composition, XRD patterns that validate the crystal structure, DLS data that indicates the distribution of particle sizes, zeta potential measurements that demonstrate colloidal stability, FTIR and Raman spectra that provide molecular information, and VSM results that exhibit magnetic behavior are among the observations that are included in this list. All the findings support the effective synthesis of iron oxide nanoparticles with Bacillus megaterium and provide a thorough description of their characteristics [27].

2.10 synthesis of iron oxide nanoparticles using iso butanol

Magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3), which have important biomedical uses such as tumor targeting and magnetic resonance imaging, are the subjects of this paper's investigation into the production and characterization of magnetic iron oxide nanoparticles. Setting the scene for the investigation, the introduction gives a thorough summary of the significance of the properties of nanoparticles and describes the different production techniques employed in earlier studies.
The synthesis procedure, which entails precipitating iron salts in Iso butanol and calcining them at various temperatures, is described in detail in the experimental section. The work methodically examines how the synthesis conditions—such as pH, calcination temperature, and iron salt concentration—affect the nanoparticles' size, shape, phase composition, and magnetic characteristics. For characterization, methods including vibrating sample magnetometry (VSM), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD) are used.
The results from FTIR spectra, magnetic hysteresis curves, SEM micrographs, and XRD patterns are shown in the results section. It goes into detail about the produced nanoparticles' crystalline structure, particle size distribution, phase transformation, and magnetic properties. The information shows how synthesis parameters affect the characteristics of nanoparticles, including how Iso butanol functions as a surfactant to regulate particle size and how calcination temperature affects phase composition and magnetic properties [28].

Table below describes the different sources and methods to synthesixe iron nanoparticles

Sl.no	Method	Nano-particle synthesized	Applications	Reference
1	Green synthesis of iron oxide nanoparticle using *Carica papaya* leaf extract	Iron oxide nanoparticle	Photocatalytic degradation of remazol yellow RR dye and antibacterial activity	[19]
2	Chemical Reduction with Palladium Ion Seeds	Iron Nanoparticles	Biomedical applications Environmental Remediation	[20]
3	Biogenic synthesis of magnetic iron	Magnetic iron oxide	Characterization, antimicrobial, antioxidant activity	[21]

	oxide nanoparticles using inedible borassus flabellifer seed coat		and *in vitro* cytotoxicity analysis	
4	Green synthesis of Iron nanoparticles using aqueous extract of Musa ornate flower sheath	Iron nanoparticles	Antibacterial activity	[22]
5	Microbial synthesis of iron-based nanomaterials	Synthesis of metal nanoparticles, with an emphasis on iron oxide nanoparticles	Industries, including technology and medicine.	[23]
6	Biocatalysis as a Green Approach for Synthesis of Iron Nanoparticles	Iron Nanoparticles	Control, efficiency, and scalability of microfluidic systems	[24]
7	One-pot green synthesis of iron oxide nanoparticles from *Bauhinia tomentosa*	Iron oxide nanoparticles	Characterization techniques to clarify the particles' structural, morphological, and magnetic features	[25]
8	Plant-Mediated Green Synthesis of Iron Nanoparticles	Iron Nanoparticles	Reducing and stabilizing agents	[26]
9	Biomimetic synthesis of iron oxide nanoparticles from *Bacillus megaterium*	Iron oxide nanoparticles	Hyperthermia therapy	[27]
10	Synthesis of Iron Oxide Nanoparticles Using Isobutanol	Iron Oxide Nanoparticles	Biomedical applications	[28]

3. RESULTS AND DISCUSSION

The burgeoning field of green synthesis techniques for iron oxide nanoparticle creation showcases a promising avenue for sustainable and efficient nanoparticle production. Leveraging the reducing and capping attributes of plant extracts, these eco-friendly methods have demonstrated efficient synthesis capabilities. Notably, nanoparticles produced using Carica papaya leaf extract exhibited potent color degradation in sunlight, hinting at their potential for environmental remediation. Moreover, their efficacy against specific cell lines and antibacterial properties suggests promising therapeutic applications, particularly in combating tumor cells.Similarly, the biocompatible magnetic iron oxide nanoparticles synthesized using B. flabellifer seed coat extract displayed exceptional radical scavenging and antibacterial activities due to the presence of polyphenols. Their cytocompatibility underscores their potential for safe and effective therapeutic interventions. Additionally, Bauhinia tomentosa leaf extract was employed to produce Fe2O3 nanoparticles, highlighting their versatility in synthesizing compounds like 1,3-diolein and immobilizing lipase, bolstered by the extract's phenolic stability. Comparative studies have consistently extolled the virtues of green synthesis over conventional methods, emphasizing its cost-effectiveness, environmental friendliness, and potential to yield nanoparticles with enhanced medicinal properties. Innovations such as the adoption of microfluidic platforms and unconventional synthesis sources like M. ornata flower sheath extract signify the field's evolution and its ability to enhance nanoparticle quality, stability, and utility. In conclusion, green synthesis stands out as a revolutionary approach to nanoparticle production, offering solutions to pressing environmental, medical, and industrial challenges. Hence, we can conclude that Green synthesis iron nanoparticles using papaya leaves is the best approach of synthesis as it requires papaya leaves that are easily available and two reagents that are inexpensive. Other methods are relatively time consuming and expensive.

4. CONCLUSION

Iron deficiency has a significant impact on a substantial portion of the global population. It is a prevalent nutritional disorder and accounts for nearly half of all cases of anemia, affecting over 2 billion individuals worldwide. Even mild and moderate levels of iron deficiency, which fall below the threshold for iron deficiency anemia (IDA), lead to compromised human functioning. Optimizing iron intake is imperative for sustaining human health, underscoring the necessity of bolstering iron levels in plant-derived foods. Through an extensive review, it has been established that integrating nanoparticles represents a superior strategy for enhancing iron content within plants. Among the various methodologies explored, the synthesis of nanoparticles derived from papaya leaves emerges as particularly promising. This approach not only offers efficacy in augmenting iron levels but also presents practical advantages, including simplicity and scalability, rendering it suitable for large-scale production. The utilization of papaya leaf-derived nanoparticles holds considerable potential for combatting iron deficiency on a global scale, meriting further research and implementation within agricultural frameworks. By leveraging this innovative technique, strides can be made towards addressing nutritional deficits and promoting better health outcomes within communities worldwide.

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