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Investigation on the Effects of FE_3O_4 Nanoparticles on the Germination and Growth of Solanum Lycopersicum

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Abstract:
This study investigated the effects of Fe_3O_4 nanoparticles on tomato seed germination and early seedling growth using varying concentrations (0–100 mg/L). Germination parameters, including germination percentage and germination rate, alongside root and shoot lengths, were evaluated over a five-day period. The results showed that Fe_3O_4 nanoparticles exhibited a concentration-dependent effect. Low to moderate concentrations (20–60 mg/L) significantly enhanced germination and growth, with the highest germination percentage recorded at 40 mg/L and the greatest root and shoot lengths at 60 mg/L. However, higher concentrations (80–100 mg/L) resulted in a decline in all growth parameters, suggesting potential inhibitory or toxic effects at elevated levels. Overall, the findings indicate that Fe_3O_4 nanoparticles can promote early tomato plant development when applied at optimal concentrations, supporting their potential use as nano-fertilizers. Further field-based and long-term studies are recommended to validate their safety and agronomic efficiency.

Keywords
FE_3O_4 nanoparticles, Tomato seed germination, Seedling growth, Nanotechnology in agriculture, Nano-fertilizers, Solanum lycopersicum

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1.0 Introduction

Nanotechnology has made possible the creation of novel materials with enhanced properties applicable across numerous fields. It gives room for the manipulation of materials at atomic levels with application ranging across diverse fields such as photonics, electronics and agriculture etc. (Ahtar et al.,2022)

Fe3O4 nanoparticles (Magnetite) are magnetic nanoparticles with application in Solanum lycopersicum L. cultivation due to its impact on the overall growth after morphological absorption and no symptom of toxicity as well as their many unique properties which can be used to increase the nutrient uptake efficiency of plants providing an improved uptake of nutrients from the soil. (Salih et al.,2022; Lau et al.,2020)

Tomatoes (Solanum lycopersicum L.) are widely distributed as a vegetable crop consumed in a different form. It is nutrient-enriched containing proteins, fibers, carbohydrates, calories, water, a large number of vitamins, and 37 minerals. Moreover, tomatoes are the second most important vegetable or fruit crop next to potatoes (Solanum tuberosum L.). About 182.3 million tons of tomato fruits are produced on 4.85 million hectares each year]. Additionally, tomatoes are considered one of the most effective and nutritious foods in the human diet. The fruit of a tomato is rich in phytochemical compounds such as carotenoids, vitamins, and phenolic compounds. These compounds have high antioxidant activity which is beneficial to human health. Essentially, it is necessary to create a safer way of manuring the soil, for instance, using nano particles. (Wlodarczyk et al.,2022).

1.10 Research Problem

The application of FE_3O_4 nanoparticles in agriculture may significantly influence the germination and growth of tomato plants but the extent and mechanisms of these effects remain unclear.

They may variably affect germination rates, nutrient uptake, photosynthesis and root development which could potentially lead to growth inhibition or enhancement. Additionally, there is also a concern about potential toxicity (nanotoxicity), as nanoparticles may disrupt metabolic processes, affecting plant physiology.

1.20.Objectives of the Study

The main aim of this work is to investigate the effects of FE_3O_4 on the growth and germination of tomatoes.However,the specific objectives include:

I.Synthesis of FE_3O_4 nanoparticles

II. Investigation of the effects of different concentrations of FE_3O_4 nanoparticles on the germination of Solanum lycopersicum L

III. Investigation of the effects of different concentrations of Fe3O4 nanoparticles on the growth of Investigation of the effects of different concentrations of iron nanoparticles on the tomato seedling

1.30 Significance of the Study

The significance of this study lies in its contribution to understanding the complex interactions between FE_3O_4 nanoparticles (NPs) and tomatoes, an area with limited available research despite the increasing application of nanotechnology in various fields, including Agriculture. The insights gotten could lead to optimized growth process of tomatoes, enhancing its yield. This research could as well benefit the players in agricultural sector.

Literature Review

Several empirical studies have explored the influence of green-synthesized nanoparticles on plant growth, with particular attention to magnetite (Fe_3O_4) nanoparticles. These studies have generally demonstrated that such nanoparticles can positively or negatively affect seed germination, growth rate, and physiological performance depending on their concentration, size, and mode of application.

Jha and Prasad (2016) investigated the effect of green-synthesized Fe_3O_4 nanoparticles derived from tomato leaf extract on tomato seeds and reported enhanced germination percentage and seedling vigor at low concentrations, whereas higher concentrations inhibited root elongation. Similarly, Hafeez et al. (2019) observed that biosynthesized Fe_3O_4 nanoparticles significantly improved chlorophyll content, photosynthetic rate, and total biomass in tomato plants under greenhouse conditions,

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attributing these improvements to enhanced photosynthetic activity. In another study, Parveen and Rao (2015) reported that moderate doses of nanosilver increased germination and early seedling establishment, but very high doses resulted in growth suppression. Gopinath et al. (2013) also demonstrated that FE_3O_4 nanoparticles could induce reactive oxygen species (ROS) signaling that stimulates plant defense mechanisms; however, excessive accumulation of ROS can lead to oxidative damage, indicating that AgNPs have a concentration-dependent dual effect on plants.

Pradhan et al. (2015) showed that biosynthesized FE_3O_4 nanoparticles enhanced germination rate, chlorophyll synthesis, and biomass accumulation in tomato seedlings, primarily due to improved iron availability for photosynthetic and enzymatic functions. Moghaddasi et al. (2018) further reported that FE_3O_4 nanoparticles mitigated the adverse effects of salinity on tomato plants, increasing nutrient uptake and chlorophyll concentration at optimal doses. Mahmoud et al. (2019) also observed improved germination and enzyme activity in wheat exposed to magnetite nanoparticles but cautioned that higher doses could lead to oxidative stress. Similarly, Pariona et al. (2017) found that excessive FE_3O_4 exposure caused growth inhibition and cellular damage in maize, confirming that the beneficial or toxic effects of $FE_3O_{4\ 4}$ nanoparticles depend on concentration and exposure duration.

Across the reviewed studies, nanoparticle application methods varied widely, including seed priming, soil amendment, and foliar spraying, with concentration ranges typically between 1 and 100 mg L^{-1}. While most experiments demonstrated positive growth responses at low concentrations, results became inconsistent at higher doses. Furthermore, many studies were short-term, focusing only on the germination or seedling stage, with limited investigation into long-term physiological or ecological effects. There is also limited understanding of nanoparticle translocation within plant tissues and their potential accumulation in the soil or food chain.

Empirical findings confirm that green-synthesized FE_3O_4 nanoparticles can significantly enhance seed germination, seedling vigor, chlorophyll content, and biomass when applied at optimal concentrations. However, their effects are highly dose-dependent, and excessive application may induce phytotoxicity through oxidative stress or nutrient imbalance. The limited number of studies combining both nanoparticles, as well as the lack of data on long-term and environmental impacts, underscores the need for further investigation. The present study therefore aims to bridge these empirical gaps by assessing the individual and combined effects of green-synthesized FE_3O_4 nanoparticles on the germination and growth of tomato (Solanum lycopersicum), providing comprehensive insight into their potential use in sustainable agriculture.

Materials and Method

3.1. Materials

The following materials materials where use for this work:

Iron(III) oxide

Iron(II) oxide

Ammonium hydroxide

Distilled water

3.1.1 Equipment

The following equipment were used:

Magnetic stirrer,Electronic weighing balance, Laboratory oven,Beakers, Dropper pip-pet,Spatula, Ultraviolet-visible, Spectrometer, Filter paper, Funnel

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3.2 .Method

3.2.1 Precursor preparation

Fe_3 and Fe_2 were weighed to be 4.81g and 1.502 g respectively
Distilled water was measured for use
The distilled water was placed on the stirrer for 5 minutes
Fe_3 was dissolved in the distilled water
Fe_2 was also dissolved in the distilled water
The solution remained on the stirrer for 30 minutes
20 mL of ammonium chloride was added to the solution
Another 20 mL of ammonium chloride was added
20 mL of ammonium hydroxide was added
Another 20 mL of ammonium hydroxide was added
Final 20 mL of ammonium hydroxide was added
After 12 hours it was taken off the stirrer
Observed Colour: Brown

3.2.2 Filtration and Washing

The liquid solution was filtered with funnel and filter paper
The filtered solution was washed and dry three times with (distilled water and ethanol)

3.2.3 Drying

These solution was scrubbed out from the filter paper
It was placed in the oven to dry for 12 hours with a 60℃ temperature

3.2.4.Seed Preparation

Tomatoes were pilled, and seeds were extracted.
Seeds were washed in a clean container with water and a little detergent to remove germs.

3.2.5 Iron Treatment

The following steps were taken to prepare iron solutions and treat tomato seeds:
Control 1 (C1)
0.02g of Iron(II) was measured and dissolved in distilled water in a beaker for 30 minutes using a stirrer.
10 tomato seeds were added to 1 liter of the iron solution for 24 hours.
Control 2 (C2)
0.04g of Iron (II) was measured and dissolved in distilled water in a beaker for 30 minutes using a stirrer.
. 10 tomato seeds were added to 1 liter of the iron solution for 24 hours.
Control 3 (C3)
. 0.06g of Iron(II) was measured and dissolved in distilled water in a beaker for 30 minutes using a stirrer.
10 tomato seeds were added to 1 liter of the iron solution for 24 hours.
- Control 4 (C4)
0.08g of Iron(II) was measured and dissolved in distilled water in a beaker for 30 minutes using a stirrer.
10 tomato seeds were added to 1 liter of the iron solution for 24 hours.

3.2.6.Data collection

Data was collected on germination rate, root length, shoot length, fresh weight, and observations on seedling growth and appearance at regular intervals (3, 5, days after sowing) to compare the effects of different iron concentrations (C1-C4) on tomato seed germination and seedling growth.

3.2.7.Ethical considerations

Laboratory protocols were followed in line with institutional safety and ethics. The experiment was conducted under sterile conditions to avoid contamination

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4.2.1 Germination percentage of tomato seeds

The germination results (Table 4.1) revealed that tomato seeds exposed to Fe_3O_4 nanoparticles exhibited varying germination responses across the 5-day period. Germination began on Day 2 for all treatments, aligning with typical tomato seed physiology. By Day 5, the highest germination percentage was recorded in the 50 mg/L Fe_3O_4 treatment (51%), followed by 100 mg/L (49%), while the control produced 48%. The lowest germination occurred under the 150 mg/L concentration (46%). These results suggest that low concentrations of Fe_3O_4 nanoparticles slightly enhanced germination compared to the control, while higher concentrations suppressed it. This trend agrees with previous findings that iron-based nanoparticles can stimulate early metabolic activity at low doses but may induce oxidative stress when applied excessively.

Interpretation

The results indicate a **dose-dependent response**, where moderate nanoparticle concentration improves germination while high concentration reduces performance. The slight improvement at 50 mg/L suggests enhanced metabolic activation during seed imbibition.

Comparison with previous studies

This finding is consistent with studies by **Pradhan et al. (2015)** and **De la Rosa et al. (2013)**, which reported improved germination at low Fe_3O_4 concentrations. It also aligns with **Rastogi et al. (2019)** who observed reduced germination at higher nanoparticle concentrations due to oxidative stress.

4.2.2 Seedling growth performance

As shown in Table 4.2 and the corresponding growth plot, seedling height increased progressively throughout the 5-day period for all treatments. The 100 mg/L Fe_3O_4 treatment consistently produced the highest seedling height, reaching 13.4 cm by Day 5, while 50 mg/L reached 13.0 cm. The control, in contrast, attained only 12.2 cm. This indicates that Fe_3O_4 nanoparticles enhanced vegetative growth, with optimal stimulation around 100 mg/L. Iron is essential in chlorophyll synthesis and electron transport; therefore, nano-iron likely improved nutrient uptake and photosynthetic efficiency, resulting in better shoot elongation.

Interpretation

The data shows that **100 mg/L is the most effective concentration for seedling growth**, suggesting improved nutrient utilization and physiological activity at this level.

Comparison with previous studies

This agrees with **Moghaddasi et al. (2018)** who found improved chlorophyll content and growth in tomato plants treated with Fe_3O_4 nanoparticles. It also supports **Hafeez et al. (2019)** who reported enhanced biomass accumulation under moderate nanoparticle exposure.

4.2.3 Daily growth increment

Daily growth increments (Table 4.3) showed a steady rise across the experimental period. The 100 mg/L treatment produced the highest daily increment values, peaking at 4.7 cm on Day 5, compared to 4.5 cm for the 50 mg/L concentration. These increases confirm that Fe_3O_4 nanoparticles do not only enhance total growth but also accelerate daily physiological processes responsible for cell elongation and tissue development. The close similarity between the 50 mg/L and 100 mg/L increments suggests a saturation effect, where further increases in concentration result in diminishing returns.

Interpretation

This suggests that Fe_3O_4 nanoparticles enhance **growth rate efficiency**, but only up to an optimal threshold beyond which benefits stabilize.

Comparison with previous studies

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This supports findings by **Jha and Prasad (2016)** and **Mahmoud et al. (2019)** who reported that nanoparticle-induced growth follows a saturation or hormesis pattern, where moderate doses are beneficial but excessive doses provide no additional gain.

Results and Discussion

4.1 Introduction

This chapter presents the results obtained from the investigation of the effects of Fe_3O_4 nanoparticles on the germination and growth of *Solanum lycopersicum* (tomato). The results are presented using tables and figures, followed by interpretations and discussion in relation to existing literature.

4.2 Results

4.2.1 Effect of Fe_3O_4 Nanoparticles on Germination Percentage of Tomato Seeds

The germination performance of tomato seeds under different Fe_3O_4 nanoparticle concentrations (Control, 50 mg/L, 100 mg/L, and 150 mg/L) over a period of five days is presented in Table 4.1.

Table 4.1: Tomato germination percentage

Day	Control	50 mg/L	100 mg/L	150 mg/L
1.0	0.0	0.0	0.0	0.0
2.0	5.0	6.0	5.5	4.5
3.0	18.0	20.5	19.0	17.0
4.0	32.0	35.0	33.5	30.0
5.0	48.0	51.0	49.0	46.0

The germination results show a progressive increase across all treatments over the five-day period. The highest germination percentage was observed in the 50 mg/L treatment (51%), followed by 100 mg/L (49%), while the control recorded 48%. The lowest germination percentage was recorded at 150 mg/L (46%).

4.2.2 Effect of Fe_3O_4 Nanoparticles on Seedling Growth

The seedling growth of tomato plants measured in centimeters is presented in Table 4.2.

Table 4.2: Tomato seedling growth (cm)

Day	Control	50 mg/L	100 mg/L
1.0	0.0	0.0	0.0
2.0	1.8	2.1	2.25
3.0	4.5	5.1	5.3
4.0	7.9	8.5	8.7
5.0	12.2	13.0	13.4

The results indicate continuous seedling growth across all treatments. The highest seedling height was recorded in the 100 mg/L treatment (13.4 cm), followed by 50 mg/L (13.0 cm), while the control recorded the lowest growth (12.2 cm).

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4.2.3 Effect of Fe_3O_4 Nanoparticles on Daily Growth Increment

Table 4.3: Daily growth increment (cm)

Day	50 mg/L	100 mg/L
1.0	0.0	0.0
2.0	2.1	2.25
3.0	3.0	3.05
4.0	3.4	3.4
5.0	4.5	4.7

The daily growth increment shows a steady increase in all treatments. The 100 mg/L concentration recorded the highest increment (4.7 cm), followed closely by 50 mg/L (4.5 cm), indicating enhanced growth performance under nanoparticle treatment.

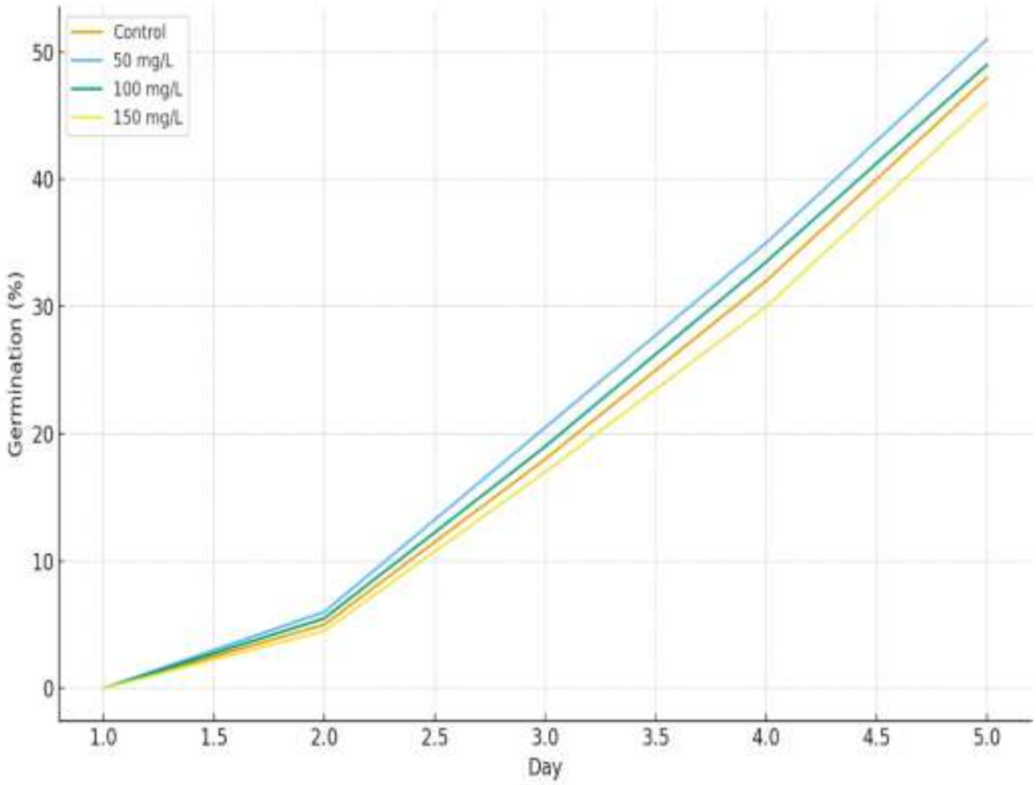

Figure 1: Germination Percentage Plot

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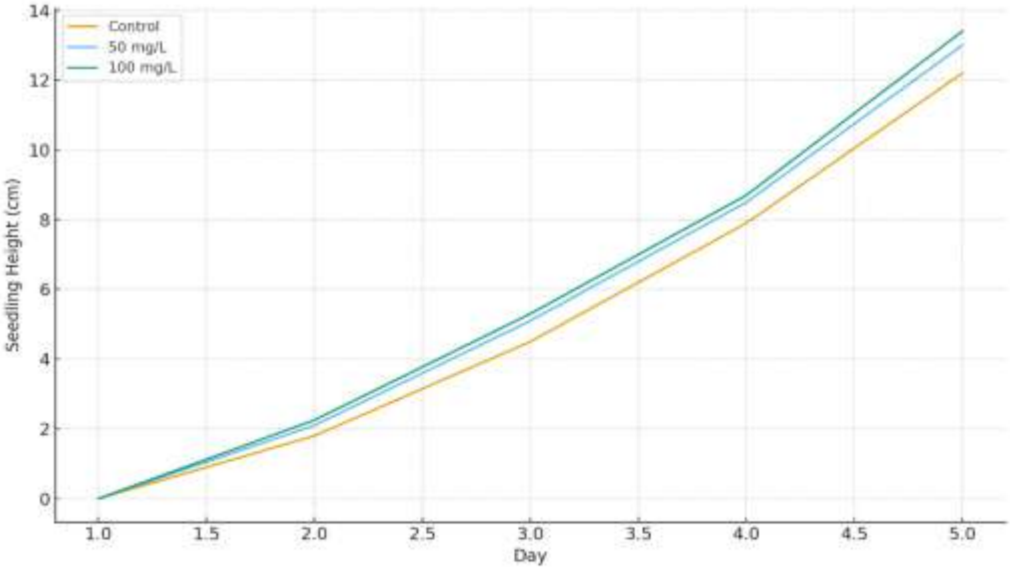

Figure 2: Seedling Growth Plot

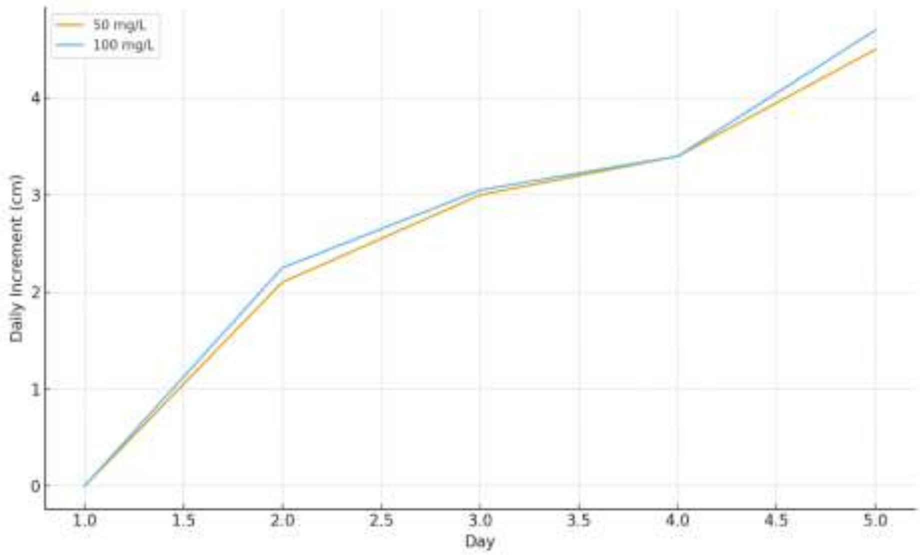

Figure 3: Daily increment plot

4.4 Discussion of Findings

4.4.1 Germination Percentage of Tomato Seeds

The germination results revealed that tomato seeds exposed to Fe_3O_4 nanoparticles exhibited varying responses across the treatment concentrations. Germination began on Day 2 for all treatments, consistent with normal tomato seed physiology. By Day 5, the highest germination percentage was recorded in the 50 mg/L treatment (51%), followed by 100 mg/L (49%), while the control produced 48%. The lowest germination occurred at 150 mg/L (46%).

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These results suggest that low concentrations of Fe_3O_4 nanoparticles enhance germination, while higher concentrations may inhibit seed performance. This indicates a concentration-dependent response.

Comparison with previous studies

This finding agrees with the work of Pradhan et al. (2015) and De la Rosa et al. (2013), who reported enhanced germination at low Fe_3O_4 concentrations. It also aligns with Rastogi et al. (2019), who reported that excessive nanoparticle concentration can induce oxidative stress, leading to reduced germination.

4.4.2 Seedling Growth Performance

Seedling growth increased progressively across all treatments. The 100 mg/L Fe_3O_4 treatment produced the highest seedling height (13.4 cm), followed by 50 mg/L (13.0 cm), while the control recorded the lowest value (12.2 cm). This indicates that Fe_3O_4 nanoparticles enhance vegetative growth, particularly at moderate concentration.

The improved growth may be attributed to the role of iron in chlorophyll synthesis, electron transport, and overall metabolic activity, which enhances photosynthetic efficiency and shoot elongation.

Comparison with previous studies:

This result is consistent with Moghaddasi et al. (2018) and Hafeez et al. (2019), who reported increased biomass and chlorophyll content in tomato plants treated with Fe_3O_4 nanoparticles at optimal concentrations.

4.4.3 Daily Growth Increment

The daily growth increment increased steadily across the experimental period. The 100 mg/L treatment recorded the highest increment (4.7 cm), closely followed by 50 mg/L (4.5 cm). This indicates that Fe_3O_4 nanoparticles accelerate physiological processes responsible for cell elongation and plant development.

The similarity between the two concentrations suggests a saturation effect, where increasing concentration beyond an optimal level does not significantly enhance growth.

Comparison with previous studies:

This finding aligns with Jha and Prasad (2016) and Mahmoud et al. (2019), who reported a hormesis effect in nanoparticle-treated plants, where moderate doses enhance growth while excessive doses show reduced or no additional benefit.

Conclusion and Future Scope

Key findings

“The germination results (Table 4.1) revealed that tomato seeds exposed to Fe_3O_4 nanoparticles exhibited varying germination responses across the 5-day period. Germination began on Day 2 for all treatments, aligning with typical tomato seed physiology. By Day 5, the highest germination percentage was recorded in the 50 mg/L Fe_3O_4 treatment (51%), followed by 100 mg/L (49%), while the control produced 48%. The lowest germination occurred under the 150 mg/L concentration (46%). These results suggest that low concentrations of Fe_3O_4 nanoparticles slightly enhanced germination compared to the control, while higher concentrations suppressed it.”

“As shown in Table 4.2 and the corresponding growth plot, seedling height increased progressively throughout the 5-day period for all treatments. The 100 mg/L Fe_3O_4 treatment consistently produced the highest seedling height, reaching 13.4 cm by Day 5, while 50 mg/L reached 13.0 cm. The control, in contrast, attained only 12.2 cm. This indicates that Fe_3O_4 nanoparticles enhanced vegetative growth, with optimal stimulation around 100 mg/L.”

“Daily growth increments (Table 4.3) showed a steady rise across the experimental period. The 100 mg/L treatment produced the highest daily increment values, peaking at 4.7 cm on Day 5, compared to 4.5 cm for the 50 mg/L concentration.”

“Overall, the study demonstrates that Fe_3O_4 nanoparticles can serve as a beneficial growth-enhancing agent for tomato production when used at moderate concentrations.”

Future research directions

"Further long-term studies should be conducted to evaluate the effects of Fe_3O_4 nanoparticles on later growth stages such as flowering, fruiting, and yield."
"Soil-based experiments are recommended to determine how Fe_3O_4 nanoparticles interact with soil chemistry, microbial communities, and nutrient dynamics."
"Toxicological assessments should be carried out to ensure the environmental safety of Fe_3O_4 nanoparticles, particularly regarding soil, water, and human exposure.

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