

Enhancement of *Amaranthus dubius* seed β -Amylase activity from the iron oxide Nanoparticle synthesized from *Azadirachta indica*

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Abstract

This research aimed to synthesize nanoparticle (NPs) through environment friendly “green synthesis” method using neem leaf extract as a reducing agent and determine the impact of different Iron Oxide Nanoparticle (FeO-NPs) concentrations on developing *Amaranthus Dubius* seeds. *Azadirachta indica* leaf extract is used as a reducing agent. The seeds were primed with FeONPs for 48 hours. 7 days after priming, the growth rate, growth characteristics, germination percentage, germination rate index, and seedling robust index were measured. The results of this study revealed that nanoprimered seedlings showed significant improvement in germination metrics. Seeds primed with 75 ppm of FeO NPs showed 70% germination, 17.5 germination index, and increased β -amylase enzyme activity (0.2274). Seed primed with 75 ppm of FeO-NP was the most effective strategy to boost germination percentage, germination index, and enzyme activity (beta amylase) while increasing starch metabolism.

1. Introduction

Green synthesis of nanoparticles (NPs) is increasingly vital due to its environmental and health benefits over traditional methods. Unlike conventional approaches, which often rely on toxic chemicals and high-energy processes, green synthesis utilizes natural materials such as plant extracts, microorganisms, and biodegradable substances. This reduces hazardous waste and minimizes environmental pollution, contributing to a cleaner, more sustainable process. Additionally, green methods typically operate under milder conditions, which lowers energy consumption and associated costs, making them economically attractive in the long run. The use of non-toxic, renewable resources also enhances safety for researchers and industrial workers. Utilizing plant extract provides a biological way to synthesize several metallic NPs precisely with distinct sizes and shapes (1).

Studies have been conducted on *Azadirachta indica* ability to produce iron oxide NPs. Many phytochemicals found in neem seeds, bark, and leaves, such as terpenoids, flavonoids, and tannins, can act as reducing agents and stabilizers while NPs are being formed. Neem leaves, as well as seed extract have been employed as a reducing agent to produce iron oxide NPs in a number of studies (2). *A. indica*, is a member of the Meliaceae family of plants having several uses in medicine Modern and traditional medicine. Terpenoids and flavanones phytochemicals function as capping and reducing agents and aid in the stabilization of NPs. Quercetin, salannin, gedunin, sodium nimbin, nimbin, nimbidin, ninbidol, and gedunin are some of the important bioactive phytochemicals in *A. indica* (3).

Neem plant extracts have shown promising results in the synthesis of iron oxide NPs, and further research in this area could lead to the development of efficient and cost-effective methods for synthesizing NPs with potential applications in various fields. In recent studies, Fe-NP has been synthesized from neem Oil has applications in photocatalytic degradation of toxic dyes (4), antifungal agent against aflatoxin-producing *Aspergillus flavus* (5), antibiofilm agent against *S. aureus* (6). Beta-amylase plays a crucial role in seed growth by facilitating the mobilization of stored carbohydrates during germination. This enzyme breaks down starches into maltose and other sugars, which are

essential for providing the energy and building blocks needed for the developing seedling. During seed germination, the embryo utilizes stored starches as a primary energy source. Beta-amylase activity is pivotal in converting these complex carbohydrates into simpler sugars that are readily available for metabolic processes. These sugars fuel the growth of the seedling, supporting critical activities such as cell division, elongation, and the synthesis of proteins and nucleic acids. Furthermore, effective beta-amylase activity ensures that seeds can rapidly and efficiently transition from a dormant state to an active growth phase. This is particularly important for crop seeds, as it influences the uniformity and speed of germination, ultimately affecting crop yield and quality. High beta-amylase activity can lead to better seedling vigor and resilience, enhancing overall plant health and productivity. Therefore, understanding and optimizing beta-amylase activity can have significant implications for agriculture and crop management, improving both seed performance and food security.

This study explores the green synthesis of iron oxide NPs using *A. indica* (Neem) leaves, with comprehensive characterization conducted through UV-Vis spectroscopy, FTIR, FE-SEM, and XRD techniques. Additionally, the research examines the application of these biologically synthesized NPs in seed priming and evaluates their impact on beta-amylase enzyme activity.

2. MATERIALS AND METHODS

2.1. Collection and Green synthesis of iron oxide nanoparticle.

Neem leaves are purchased from the local market and given a thorough washing in distilled water to get rid of any debris or pollutants. After drying, the leaves are crushed into a fine powder. To extract the phytochemicals from the leaves, 10g of powder and 100ml of distilled water are combined and heated to 80°C for five minutes. FeO NPNPs are made using the liquid that remains after the extract has been filtered to eliminate any solid particles. The solution is centrifuged for 5 minutes at 1200 rpm. 50 ml of 0.05M solutions of FeCl₃ is added to the sample and stirred for 15 minutes at 80⁰ C. 50 ml of 0.1M NaOH is added and stirred and the temperature is lowered to 20⁰ C. The solution color changes from light brown to dark brown, indicating the formation of NPs. The spectrophotometric reading of the sample is 333.5nm (0.05M) (Fig. 1).

2.2 Seed Priming

Amaranthus dubius (spinach) seeds used in this study were procured from a licensed local vendor, who obtained them from Kerala Agricultural University, Padanakkad, India. As the seeds were commercially available and not collected directly from the wild or institutional source by the authors, no specific collection permits or licences were required. FeO NP concentrations of 10 ppm (1mg/100ml), 25 ppm (2mg/100ml), 50 ppm (5mg/100ml), 75 ppm (7.5mg/100ml), and 100 ppm (10mg/100ml) were mixed with 100 ml of distilled water and ultrasonically treated for 20 minutes at 30°C. Ten spinach seeds were

then put in each beaker at varying concentrations and incubated for 24 hours. There were 6 treatments and each treatment has 3 repeats with total 18 glass petri dishes in total. Seeds were allowed to germinate on two layers of filter paper placed in a 90 mm diameter glass petri dishes. The filter paper in petri dishes were kept wet condition by covered with approximately 10 ml of distilled water. The petri dishes were placed in room temperature and the relative humidity was set at 70% .Germinated seeds were investigated; the shoot length of all germinated seeds' was recorded for 7 days, and growth characteristics such as germination %, germination rate index, and seedling robust index were determined. The control has merely 100 mL of distilled water and 10 seeds in each batch ().

2.3 β -Amylase Enzyme Assay

Five milligrams of germinated seeds are mashed with a motor and pestle in 2ml of 0.05M phosphate buffer before centrifugation for 15 minutes at 10,000 rpm at 40°C. Add 1 mL of 0.05 phosphate buffer to the pellet and centrifuge for 15 minutes at 10,000 rpm. Each test tube should contain 1.5 ml of diluted enzyme and up to 2 ml of distilled water. Add one ml of DNS reagent to each test tube. Incubate the test tube at 37⁰ degrees Celsius for 15 minutes. Add 1 mL sodium-potassium tartrate. Read the absorbance at 540 nm. Using a motor and pestle, crush 5 mg of germinating seeds with 2 mL of 0.05 M phosphate buffer and centrifuge at 10,000 rpm for 15 minutes at 4° C. Add 0.5 mL of 10% TCA to the supernatant and centrifuge at 5000 rpm for 5 minutes to precipitate the protein. Dissolve the particles in 0.1 N NaOH. Add 5 mL of the alkaline copper sulfate reagent combination and wait 10 minutes. Add 0.5 ml FC reagent and incubate for 30 minutes in the dark. Determine the absorbance at 660 nm.

2.4 Characterization of Nanoparticle

An aliquot of synthesized FeO NP was initially characterized by a UV-visible spectrophotometer in the wavelength range of 200–800 nm with a Shimadzu spectrophotometer (Model UV1900, Shimadzu, Kyoto, Japan). Fourier transform infrared spectroscopy (FTIR) analysis was carried out (Perkin Elmer). X-ray diffraction (XRD spectrum using the XRD method as per the standard experimental procedure was performed using (miniflex 600C 6G Desktop X-RAY Diffractometer). Surface morphology, shape of nanoparticle, and elemental composition of FeO-NP were analyzed through field emission scanning microscope (FESEM) HR-FESEM (GEMINI 300, Carl Zeiss, Germany).

3. Results and Discussion

FeO-NP has been found to play a crucial role in enhancing β -amylase activity. These NPs act as catalysts, significantly accelerating enzymatic reactions involved in the starch breakdown. Through their high surface area-to-volume ratio, FeO-NP provides more active sites for enzyme-substrate interactions, promoting the conversion of starch into fermentable sugars by beta-amylase (7).

3.1 Characterization of FeO-NP

When aqueous *A. indica* leaf aqueous extract was added, the iron salts changed color from pale yellow to brilliant orange, then black. The hue of the solution altered as a result of the presence of FeO-NPs

formed by iron salt reduction. The color of the reaction mixture did not alter for around 10 minutes after the initial color shift. This revealed a complete reduction of the iron salts present in the reaction mixture. The subsequent UV-visible spectrum research validated the formation of FeO-NPs (Fig. 1). Terpenoids and flavonoids of *A. indica* leaf extract might function as reducing agents. The presence of a prominent peak at 333nm was attributed to the stimulation of surface plasmon vibrations in iron oxide NPs.

Figure 2-A: UV-visible absorption spectra of iron oxide NPs, B: FTIR spectra of Neem leaf extract, C: FTIR spectra of synthesized iron oxide NPs, D: XRD pattern of iron oxide nanoparticle, E: FESEM image of synthesized iron oxide nanoparticle.

FTIR analysis was performed on *A. indica* leaf extract to assess the presence of flavanones and terpenoids. The O-H stretching and bending vibrations of the amine groups NH₂ and OH, as well as the overlap of the stretching vibrations attributed to the molecules' water and phenolic groups, can be seen in the strong stretching band at around 3332 cm⁻¹. The extract exhibited an adsorption peak in the FTIR spectra at 1600 cm⁻¹ (Fig. 2) and 1400 cm⁻¹, 1000 cm⁻¹, which might be attributed to amide C = O stretching, indicating the presence of a -COOH group and C = N stretching.

According to the FTIR results, the reduction of iron ions that occurs in the *A. indica* leaf extract together with the phenolic compounds may be the probable mechanism for the synthesis of FeO-NPs (3). XRD results displayed that FeO-NP is homogeneous, spherical with sizes 31.71 and 58.29nm as well as amorphous in nature (8).

3.2 Germination Percentage and Index

Studies have shown that seed nano-priming has numerous benefits, including improved plant growth and development, higher production, and better nutritional content in food (Table 1). One of the most crucial phases in the establishment of plants in agriculture, germination is crucial for crop quality (9, 10). The quick growth of seedlings guarantees that the leaves and roots elongate quickly, which promotes nutrient intake, transport through transpiration flow, and biomass production (11).

Priming the seed with 75 ppm FeO-NP accelerated early germination. In the control group, the growth index and growth percentage were 50% and 7.5, respectively. All of the nano-primed *Amaranthus* seedlings generated exhibit typical phenotypic features and show no evidence of toxicity. Growth percentage, growth index, and enzymatic activity all increased following the 75 ppm nano priming treatment. The standard deviation of β -amylase enzyme-specific activity is 0.2274, indicating strong activity at a concentration of 75 ppm. Growth percentage (Table 2), growth index, and enzymatic activity all increased following 75 ppm nano priming treatment.

Priming and incubating the seed for 5 days with 10 ppm exhibited 40% germination and 10 germination index, 25ppm 60% and 15 germination index, 50ppm 50% germination 12.5 germination index, 75ppm 70% germination and 17.5 germination index, 100ppm exhibited 50% germination 12.5 germination index respectively (Fig. 3, Table-3).

Table 1
Measurement of shoot length of *A. dubius* at different time intervals

Sample	Control	10ppm	25ppm	50ppm	75ppm	100ppm
24 hrs	2.3	1	1.5	1	2.1	1.7
48 hrs	2.7	2	2.9	3	3.2	2.2
72 hrs	2.7	3.3	3.4	3.7	3.9	3.4
96 hrs	2.9	3.6	3.7	4	4.2	3.7
120 hrs	3.8	3.8	3.9	4.2	4.5	3.9
Growth in cm						

Table 2
Germination percentage of *A. dubius* at different concentrations of FeO-NP

Concentration	Control	10ppm	25ppm	50ppm	75ppm	100ppm
Seeds germinated	5	4	6	5	7	5
Total seeds	10					
Germination (%)	50	40	60	50	70	50

Table 3
Germination index of *A. dubius* at different concentrations Of FeO NP

Concentration	Control	10ppm	25ppm	50ppm	75ppm	100ppm
Germination %	30	40	60	50	70	50
Germination period	4					
GI	7.5	10	15	12.5	17.5	12.5

Priming of *Amaranthus* seeds with 75 ppm FeO NPs (NP) yielded exceptional results in terms of seed development, germination index, and beta-amylase activity when compared to other primed treatments and the control at 48th hour.

The germination index quantifies the speed and uniformity of seed germination. Seeds treated with 75 ppm FeO NP exhibited superior germination rates and more uniform development. This improvement can be attributed to the enhanced physiological conditions provided by the NPs. FeO NPs likely facilitated better water uptake by the seeds, which is crucial for breaking dormancy and initiating germination. Additionally, these NPs might have optimized the internal environment of the seeds, ensuring that the conditions are more favorable for rapid germination and seedling growth.

Beta-amylase is essential for breaking down stored starches into maltose and glucose, which are critical energy sources during germination. Increased beta-amylase activity in seeds primed with 75 ppm FeO

NP indicates a more efficient conversion of starches into sugars. This enhanced enzymatic activity provides the necessary energy for seedling growth, supporting better root and shoot development. The NPs likely acted as catalysts or stimulants, boosting the synthesis or efficiency of beta-amylase, thereby accelerating the breakdown of starch reserves.

The remarkable performance of the 75 ppm FeO NP treatment compared to other primed treatments and the control suggests that this specific concentration and duration are optimal for improving seed performance. Other treatments might not have had the same impact on enzyme activity or could have been less effective in stimulating seed growth.

In conclusion, priming *Amaranthus* seeds with 75 ppm FeO NPs significantly enhances germination and development by improving beta-amylase activity and overall seed metabolism, demonstrating the potential of NPs as effective priming agents.

Biogenic synthesized CuO and ZnO NPs using *Stenotrophomonas maltophilia* to study their impact on *Amaranthus hybridus* seed germination and plant growth and as nanofertilizer (12, 13). Similar studies found that nanopriming wheat seedlings with biosynthesized AgNPs (1 mg L^{-1}) reversed the negative effects of salt stress and enhanced wheat seed germination rates (14).

Rai-Kalal and Tomar (15) used silicon oxide NPs (15 mg L^{-1}) and seed treatment with TiO_2 NPs at low concentrations (16) resulting in increased water absorption, amylase activity greater seed germination in *Zea Maize*. Furthermore, it was shown that priming maize (*Zea mays* L.) seeds with 1000 mg L⁻¹ mango peel NPs (NPPs) may significantly boost germination percentage and alleviate salinity-induced seed germination loss (17). To improve seed germination and seedling vigor using nano-priming seeds are initially soaked in NPs, dried, and then subjected to stress again, memories are primed in the seeds, which may later be triggered to boost stress resistance while the seeds germinate (18; 19). Nano-priming develops nanopores for the absorption of NPs (NPs), which allows the seeds to absorb more water. Furthermore, NPs alter seed metabolism and promote the production of aquaporin genes. Nano-priming produces reactive oxygen species (ROS) like as superoxide radicals (O_2^-) and hydrogen peroxide (H_2O_2), which function as signaling molecules to trigger metabolic pathways crucial to germination (20).

Conclusion

In conclusion, the use of iron oxide NPs (FeO NPs) at a concentration of 75 ppm has demonstrated significant benefits for seed germination and growth, highlighting their potential as a valuable tool in agriculture. These NPs have been shown to enhance several key aspects of seed performance, including germination index, growth, and beta-amylase activity, underscoring their efficacy in improving plant development.

The positive effects of FeO NPs on the germination index and seedling growth are indicative of their ability to optimize the germination process. The 75 ppm concentration appears to provide an ideal

balance, enhancing water uptake and creating a favorable environment for seeds to transition from dormancy to active growth. This results in more rapid and uniform germination, which is crucial for maximizing crop yields and ensuring consistent plant establishment. The observed increase in beta-amylase activity with FeO NP treatment supports the hypothesis that these NPs enhance enzymatic processes critical for seed metabolism. Beta-amylase plays a vital role in breaking down starch reserves into sugars, which are essential for seedling energy. The elevated enzyme activity at the optimal concentration of 75 ppm suggests that FeO NPs effectively stimulate metabolic pathways, leading to improved energy availability for seedling development. The combination of 75 ppm FeO NPs and a 48-hour priming period appears to provide the best results, indicating that this specific dosage and duration are optimal for enhancing seed physiological and biochemical activities. This concentration likely maximizes the benefits without causing any detrimental effects, promoting efficient enzymatic action and growth. The 48-hour period allows sufficient time for the NPs to exert their effects on seed metabolism and development. These findings emphasize the potential of iron oxide NPs as a powerful priming technique in agriculture. By improving seed germination, growth, and metabolic activity, FeO NPs can contribute to higher agricultural productivity and more robust plant development. Their use could lead to better crop yields, enhanced seedling vigor, and overall improvements in crop management practices.

Declarations

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Author contributions

APG, DA, and RV: designed, conducted experiments, and drafted the manuscript. RV and SNB: Supervised the entire work and edited the manuscript. Arp, ASB, MF, and KRM: Statistical analysis, writing the first draft, and revising this manuscript. All authors have read and agreed to the published version of the manuscript.

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Data availability Data will provide on request to corresponding author.

Ethics approval and consent to participate Prior to the commencement of the experiment, all necessary permissions were obtained from the Principal, SDM College (Autonomous) & Head, Department of Biotechnology, SDM College (Autonomous), Ujire to conduct the research involving the utilization of *Amaranthus dubius*, a commonly cultivated plant species. As such, no license/permission required to collect the plant material for research or study purposes.

Competing interests The authors declare no competing interests

Ethical approval No experiment was done on humans or animals.

Conflict of Interest The authors declare no conflict of interest.

References

1. Bhat, J.A., Faizan, M., Bhat, M.A., Huang, F., Yu, D., Ahmad, A., Bajguz, A., Ahmad, P. Defense interplay of the zinc-oxide NPs and melatonin in alleviating the arsenic stress in soybean (*Glycine max* L.). *Chemosphere*, 2022; 288: 132471.
2. Islas JF, Acosta E, Zuca G, Delgado-Gallegos JL, Moreno-Treviño MG, and Escalante B. An overview of Neem (*Azadirachta indica*) and its potential impact on health. *Journal of Functional Foods*. 2020;74:104171.
3. Zambri NDS, Taib NI, Abdul Latif F, Mohamed Z. Utilization of neem leaf extract on biosynthesis of iron oxide NPs. *Molecules*. 2019;24(20):3803.
4. Eswaran SG, Stalin T, Thiruppathi D, Madhu M, Santhoshkumar S, Warchol J, et al. One-pot synthesis of carbon dots from neem resin and the selective detection of Fe (ii) ions and photocatalytic degradation of toxic dyes. *RSC Sustainability*. 2024;2:635-45.
5. Qadir Ahmad A, Attique N, Ali R, Abbas W, Nadeem M, Junaid M, et al. Green synthesis and characterization of Fe/Mg NPs for their potential applications against aflatoxogenic *A. flavus*. *Results in Chemistry*. 2024;7:101312.
6. Mohaidin NLM, Aris F, Amin IM, Zain NM, Yunus NM, Izza N. Antibiofilm property of green synthesized iron oxide NPs from neem leaves. *Journal of Sustainability Science and Management*. 2022;17(3):279-90.
7. Afzal S, Sharma D, Singh NK. Eco-friendly synthesis of phytochemical-capped iron oxide NPs as nano-priming agent for boosting seed germination in rice (*Oryza sativa* L.). *Environmental Science and Pollution Research*. 2021;28:40275-87.
8. Subha A, Shalini MG, Sahu B, Sahoo SC. Structural transformation and magnetic properties of copper ferrite NPs prepared by sol–gel method. *Journal of Materials Science: Materials in Electronics*. 2018;29:20790-9.
9. Acharya P, Jayaprakasha GK, Crosby KM, Jifon JL, Patil BS. Nanoparticle-mediated seed priming improves germination, growth, yield, and quality of watermelons (*Citrullus lanatus*) at multi-locations in Texas. *Scientific reports*. 2020;10(1):5037.
10. Abbasi Khalaki M, Moameri M, Asgari Lajayer B, Astatkie T. Influence of nano-priming on seed germination and plant growth of forage and medicinal plants. *Plant growth regulation*. 2021;93(1):13-28.
11. Chandrasekaran U, Luo X, Wang Q, Shu K. Are there unidentified factors involved in the germination of nanoprimered seeds? *Frontiers in Plant Science*. 2020;11:546690.

12. Francis DV, Sood N, Gokhale T. Biogenic CuO, and ZnO NPs as nano fertilizers for sustainable growth of *Amaranthus hybridus*. *Plants*. 2022;11(20):2776.
13. M Faizan, A Faraz, M Yusuf, ST Khan, S Hayat. Zinc oxide nanoparticle-mediated changes in photosynthetic efficiency and antioxidant system of tomato plants. *Photosynthetica*. 2018; 56:678-686.
14. Abou-Zeid H, Ismail G. The role of priming with biosynthesized silver NPs in the response of *Triticum aestivum* L to salt stress. *Egyptian Journal of Botany*. 2018;58(1):73-85.
15. Rai-Kalal P, Tomar RS, Jajoo A. Seed nanoprimering by silicon oxide improves drought stress alleviation potential in wheat plants. *Functional Plant Biology*. 2021;48(9):905-15.
16. Feizi H, Rezvani Moghaddam P, Shahtahmassebi N, Fotovat A. Impact of bulk and nanosized titanium dioxide (TiO₂) on wheat seed germination and seedling growth. *Biological trace element research*. 2012;146:101-6.
17. Elkhatib E, Attia MG, Mahdy AM, Mostafa RA. Priming with mango peels NPs enhances seed germination of maize (*Zea mays* L.) under salt stress. *Alexandria Science Exchange Journal*. 2019;40 (OCTOBER-DECEMBER):767-80.
18. Pramanik B, Sar P, Bharti R, Gupta R, Purkayastha S, Sinha S, et al. Multifactorial role of NPs in alleviating environmental stresses for sustainable crop production and protection. *Plant Physiology and Biochemistry*. 2023:107831.
19. M Faizan, A Faraz, and S Hayat. Dose-dependent response of epibrassinolide on the growth, photosynthesis, and antioxidant system of tomato plants. *Indian Horticulture Journal*. 2018;8(2 & 3); 68-76.
20. M Faizan, P Alam, VD Rajput, A Faraz, and S Afzal. Nanoparticle mediated plant tolerance to heavy metal stress: what we know?. *Sustainability*. 2023; 15(2); 1446

Figures

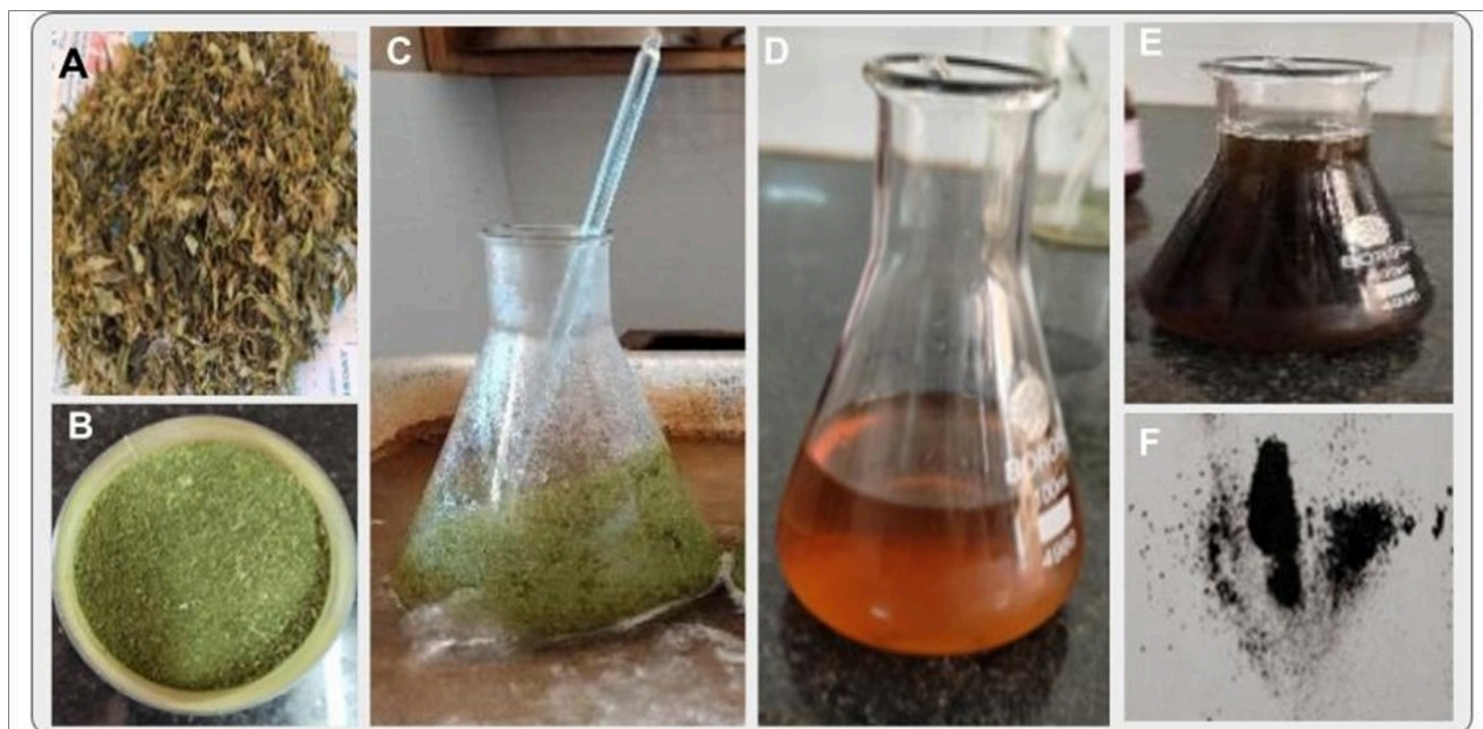


Figure 1

Synthesis of iron oxide nanoparticle from *Azadirachta indica* leave. A: Dried Neem Leaves, B: Powdered Neem Leaves, C: Neem Solution (Neem Leaves Powder + 100 mL D.H₂O + Boiled at 80⁰ C for 5 min, D: Neem Leaves Extract (Solution C centrifuged at 1200 rpm for 5 min), E: FeO Nanoparticle Solution (50 mL of 0.05M FeCl₃, 50 mL 0.1N NaOH, boiled at 80⁰ C for 15 min, F: FeO Nanoparticle Powder (Dried for 24 hour)

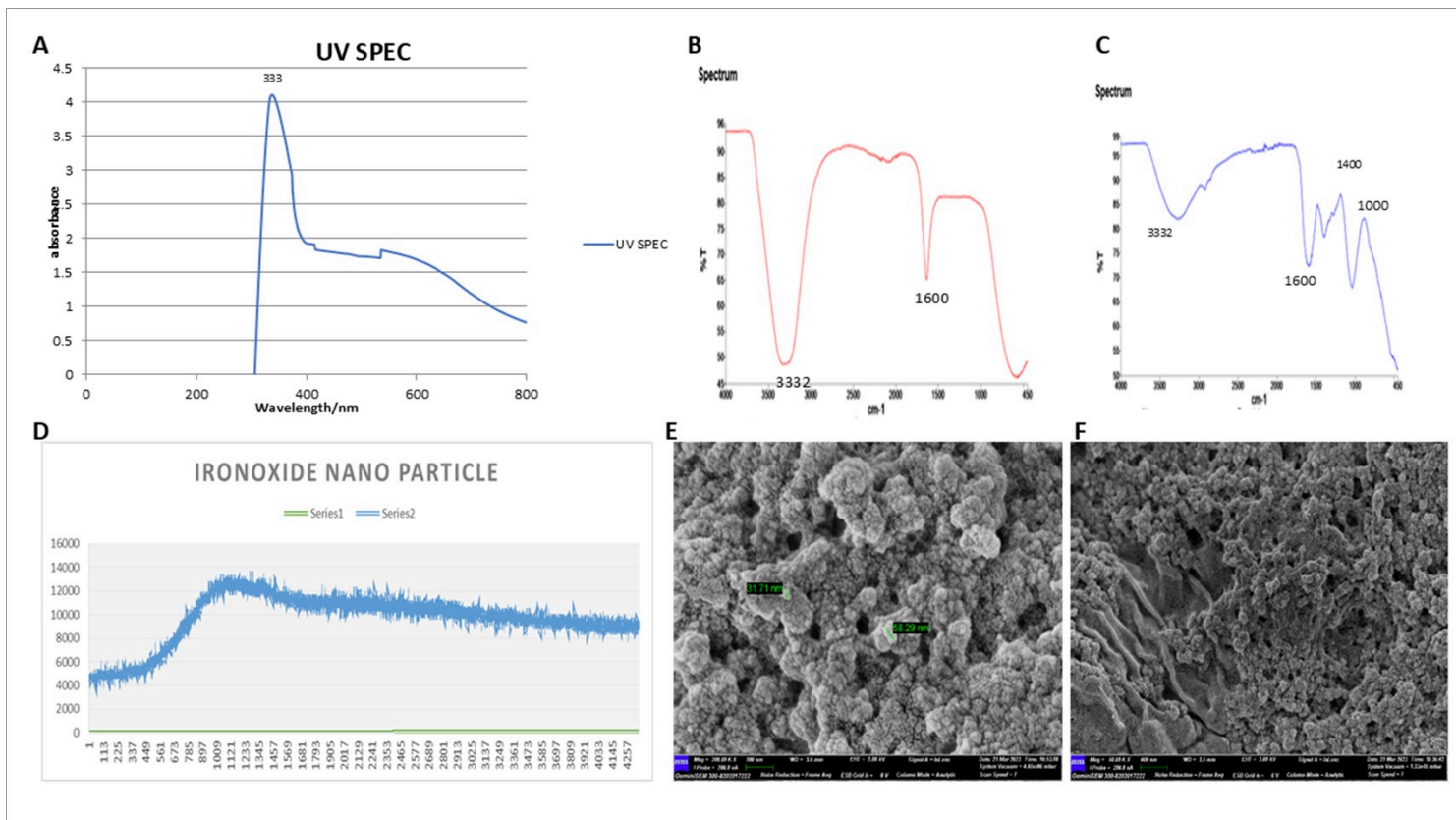


Figure 2

Characterization of Nanoparticle. A: UV-visible absorption spectra of iron oxide NPs, B: FTIR spectra of Neem leaf extract, C: FTIR spectra of synthesized iron oxide NPs, D: XRD pattern of iron oxide NPs, E & F: SEM image of synthesized iron oxide nanoparticle

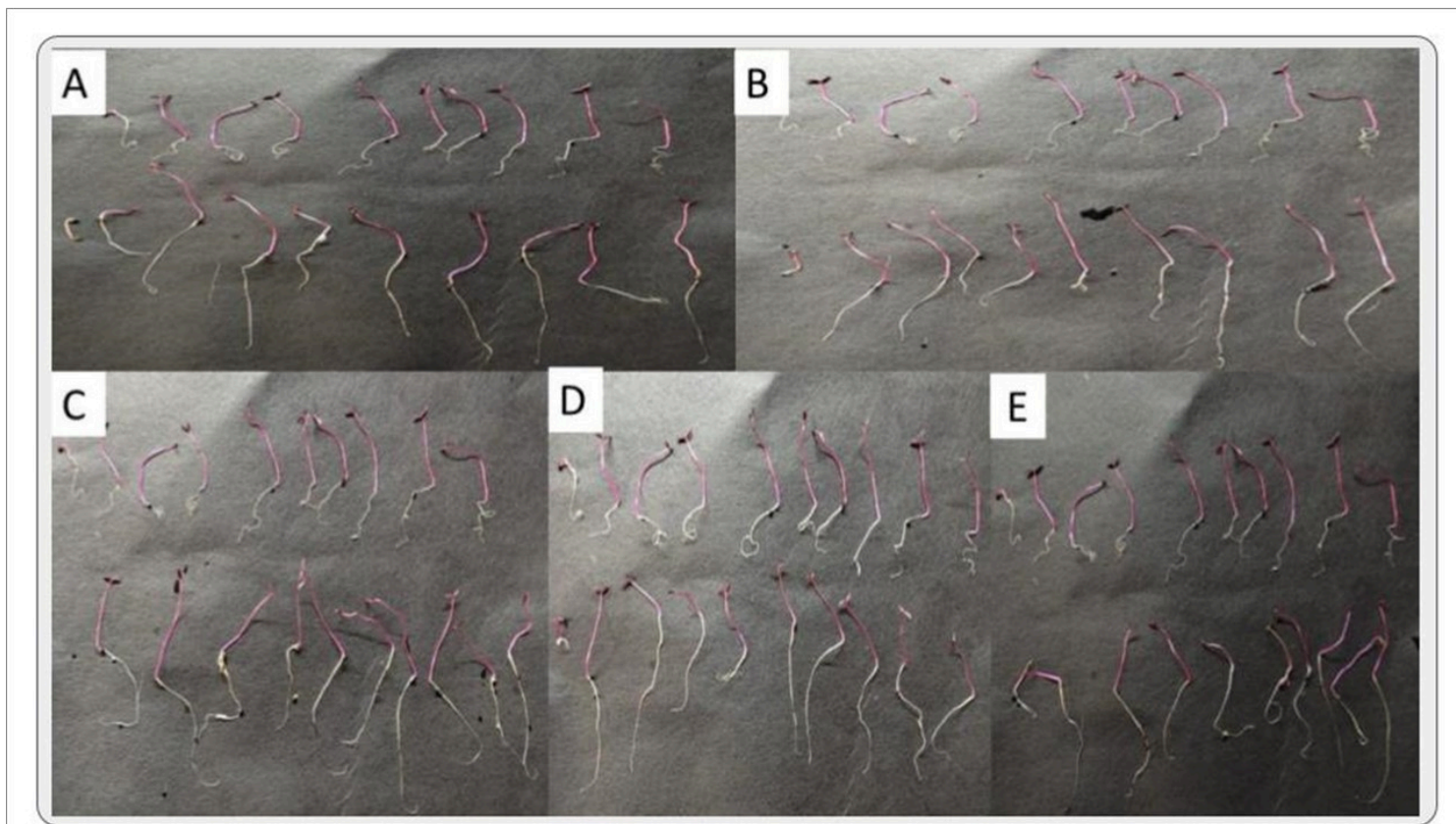


Figure 3

Germinated nanoprimed *Amaranthus* seed. Above-Control, Below-Primed seed. A: 10 ppm, B: 25 ppm, C: 50 ppm, D: 75 ppm, E: 100 ppm