Biogenic Synthesis of Zinc & Nickel Oxide Nanoparticles for Agriculture Application

A DISSERTATION

SUBMITTED IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

MASTER OF SCIENCE

IN

APPLIED CHEMISTRY

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CANDIDATE'S DECLARATION

I Kaushik Mishra (23/MSCCHE/51) and Umang(23/MSCCHE/66) students of MSc. (Chemistry) hereby declare that the project Dissertation titles "**Biogenic synthesis of Zinc & Nickel Oxide nanoparticles for agricultural application"** which is submitted by us to the Department of Applied Chemistry, Delhi Technological University, Delhi in the partial fulfilment of the requirement for the award of the degree of Master of Science, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title or recognition.

Place: Delhi **KAUSHIK MISHRA**

Date: June, 2025

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<u>CERTIFICATE</u>

I/We hereby certify that the project Dissertation titled "**Biogenic synthesis of Zinc & Nickel Oxide nanoparticles for agricultural application"** which is submitted by Kaushik Mishra (23/MSCCHE/51) and Umang (23/MSCCHE/66), Department of Applied Chemistry, Delhi Technological University, Delhi in partial fulfilment of the requirements for the award of the Master of Science, is a record of the project work carried out by the student under my supervision. To the best of my/our knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi Dr. POONAM SINGH

Date: June, 2025 **SUPERVISOR**

Dedicated

To

My Family

ACKNOWLEDGEMENT

In gratitude for all your contributions to this project thesis, we wish to extend our deepest thanks to each of you.

Our first and foremost gratitude goes out to our supervisor Dr. Poonam Singh, Assistant Professor, Department of Applied Chemistry, Delhi Technological University, Delhi, for Supporting, encouraging, and guiding us throughout our research process. Throughout this project, their expertise, insights, and feedback played an important role.

We are also grateful to the faculty members of Department of Applied Chemistry, Delhi Technological University, Delhi, for their valuable input and feedback on our project thesis. Their suggestions and comments have helped me to refine our ideas and improve the overall quality of this work.

We want to thank the honourable Prof. Prateek Sharma, Vice Chancellor of the Delhi Technological University and Prof. Anil Kumar, Head of the Department of Applied Chemistry for their kind permission to work in the Department of Applied Chemistry and providing utilities for the completion of this project.

We also wish to express our appreciation to all the research scholars, especially Ms.Sarla Yadav, Ph.D. Research Scholar of Department of Applied Chemistry, Delhi Technological University, Delhi, for their valuable assistance throughout this research work

Last but not least, we would like to thank all the participants who generously contributed to this research project. This work would not have been possible without their cooperation and support.

KAUSHIK MISHRA

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ABSTRACT

The green synthesis of transition metal oxide nanoparticles (NPs) presents an environmentally responsible and innovative pathway for advancing sustainable nanotechnology. Among various eco-friendly methods, plant extract-mediated synthesis has gained prominence due to its minimal environmental footprint, reduced energy requirements, and avoidance of toxic reagents. In present research, Zinc oxide nanoparticle (ZnO) & Nickel Oxide nanoparticles (NiO) were produced using plant extracts from *Citrus sinensis* peel and *Morus alba* leaves, which acted as both reductant and stabilizing agents. This phytochemical-assisted technique circumvents the use of hazardous chemicals and promotes cleaner production processes. The active biomolecules present in the extracts enabled effective diminution and stabilization of metal ions, leading to the generation of stable, crystalline nanoparticles under mild reaction conditions. A detailed characterization of the synthesized nanoparticles was performed using PXRD, FTIR, and zeta potential techniques. Structural and morphological analyses confirmed high crystallinity, phase purity, and well-defined shapes and sizes of synthesised nanoparticles. FTIR results further highlighted the role of specific functional groups in nanoparticle formation and stabilization. The synthesised NPs are further employed for agriculture application that is the growth of pea plant and it was observed that the sample containing plant extract exhibit more efficiency towards the faster growth of pea plant rather than chemically synthesised nanoparticles. This approach provides a scalable, cost-efficient, and non-toxic advanced synthetic methods, significantly reducing ecological impact. The resulting nanoparticles exhibit promising potential for applications in biomedical fields, catalysis and eco-friendly purification, underlining the effectiveness of plant-derived extracts in sustainable nanomaterial development.

Keywords: Green synthesis, ZnO, NiO NPs, Citrus sinensis extract, Morus alba extract, Agriculture, sustainable nanotechnology.

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LIST OF ABBREVIATIONS

NiO	Nickel oxide
ZnO	Zinc oxide
NAOH	Sodium hydroxide
DI water	Deionized water
FTIR	Fourier Transform Infrared Spectroscopy
XRD	X-Ray Diffraction
g	Grams
hrs	Hours
IR	Infrared
kV	Kilovolt
M	Molar
pH	Potential of Hydrogen
NPs	Nanoparticles
nm	Nanometer
rpm	Revolution Per minute
eV	Electron volt
atm	Atmosphere

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Nanotechnology has revolutionised various industrial sectors, including chemical, mechanical, pharmaceutical and food processing industries, while also playing a considerable role in computing, power generation, machine learning, drug delivery, optics and environmental science[1]. This field of study facilitates the synthesis of materials with superior characteristics, increasing efficiency, minimising human effort and broadening their applicability across diverse sectors. With the advancements in nanotechnology, Metal Oxide Nanoparticles (MONPs) are gaining importance due to their superior physiochemical features, such as high surface area, increased reactivity, adjustable chemical and thermal stability, and superior porosity compared to traditional Metal Oxide NPs (MONPs)[2,3]. These NPs can be synthesised using diverse methods such as hydrothermal, sol-gel, microwave-irradiation, laser ablation, etc

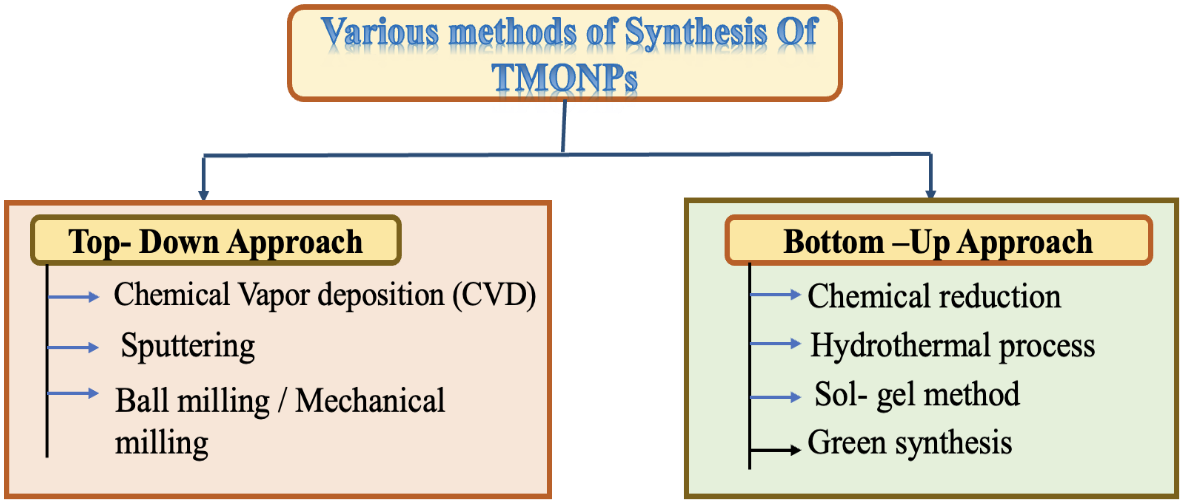
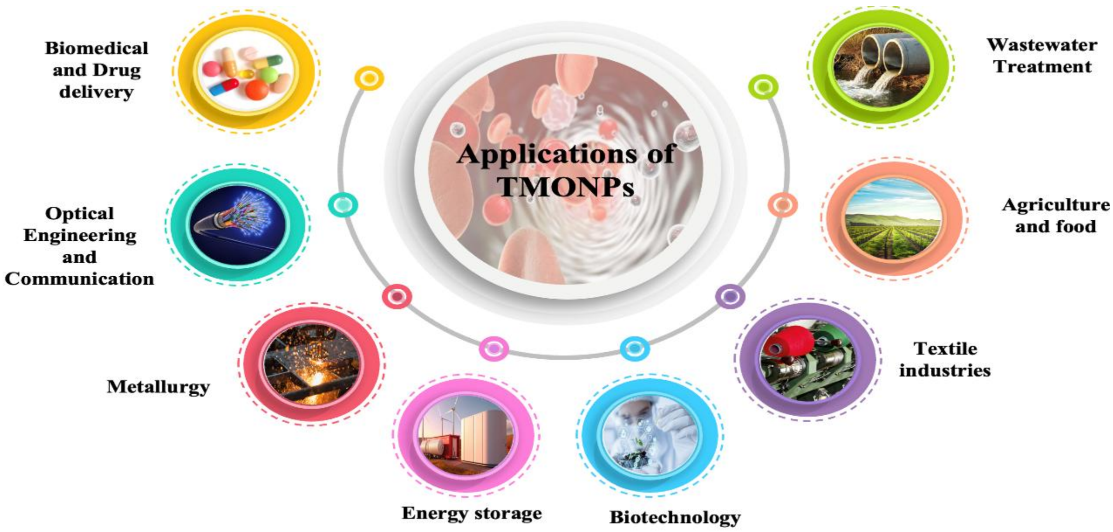


Fig 1.1 Various approaches to synthesis Metal oxide NPs

However, these traditional methods engage in the use of toxic precursors, entail high-cost, time-consuming, energy-intensive processes and generate toxic byproducts, presenting considerable challenges to sustainability and environmental safety[4,5]. Addressing these issues is essential for the responsible advancement and utilisation of nanomaterials. Continuous research, strict regulations, and established safety protocols are essential in mitigating these concerns attributed to the extensive use of NPs.

Green synthesis has emerged as an eco-friendly advanced synthesis approach, obviating the necessity for toxic chemicals and energy-intensive methods. The green synthesis approach uses plant extracts to synthesise MMONPs, providing cost-effectiveness and environmental sustainability and rendering it particularly suitable for agricultural, biomedical and wastewater treatment applications. Researchers have investigated diverse bioresources for green synthesis, encompassing plant components (bark, leaf, stem, root, flower, seed, tubers and fruits)[7,8] and microorganisms (algae, fungi, and bacteria)[9,10]. Plant and animal-derived bioresources are favoured for their abundant bioactive compounds—alkaloids, flavonoids, terpenoids, and triterpenoids—that act as natural capping and reductant in the synthesis of NPs. For instance, Jabeen et al. carried out the environmental friendly synthesis of Copper Oxide NPs from the leaf extract of Aloe vera. The synthesised CuO NPs demonstrated remarkable photocatalytic and antibacterial properties[9]. Arnab et al. carried out the green synthesis of iron doped zinc oxide nanoparticles and studied the impact of Fe@ZnO NPs in terrestrial plants . Kashama et al. synthesised chitosan encapsulated Nickel oxide nanoparticles with application in enhancing wheat crop production.



However, existing green synthesis techniques often suffer from reproducibility issues, stability concerns, and limited scalability, necessitating the exploration of novel bioresources. An effective and environmentally responsible substitute for traditional chemical synthesis methods is the biogenic production of metallic oxide nanoparticles by utilizing extracts based on plants. Because of their rich phytochemical profiles and ease of access, *Morus alba* (white mulberry) and *Citrus* × *sinensis* (orange) were chosen as biogenic agents in this investigation.

Numerous bioactive substances, including flavonoids, phenolic acids, tannins, and alkaloids, are found in *Morus alba*, a plant that is widely grown for its therapeutic and agricultural uses. During synthesis, these phytochemicals are essential for stabilizing nanoparticles and lowering metal ions. *Morus alba's* antioxidant-rich leaves are a good green precursor for the production of zinc oxide (ZnO) nanoparticles because they aid in the effective nucleation and capping processes.

Flavonoids, polyphenolic chemicals, and natural acids are abundant in the peel of *Citrus* × *sinensis*. Stable metal oxide nanoparticle production is aided by these components' potent reducing and chelating qualities. By recycling agricultural waste, the use of orange peel not only provides a sustainable method for creating nickel oxide (NiO) nanoparticles but also aids in waste vaporization. Both liquid and powdered plant extracts were utilized, providing flexibility in synthesis methods. Their participation guarantees a more environmentally friendly synthesis process while improving the functional performance of the final nanoparticles, particularly in applications like agricultural improvement and photocatalysis. Therefore, in nanotechnology, the combination of *Morus alba* and *Citrus* × *sinensis* is consistent with the concepts of green chemistry and circular economy. Limited research has proven the efficacy of *Morus Alba*-mediated nanoparticle biosynthesis.

Many plant species, seed germination and plant development are greatly enhanced by the use of nanoparticles in agriculture, which also lowers the need for excessive pesticides and fertilizers. Seed priming has been recognized as one of the many applications of nanoparticles in modern times to enhance plant development and yield [10]. The traditional yet simple and effective technique of seed priming raises the proportion of germination, the health of the seedlings, and the plant's tolerance to climate change, all of which increase output.

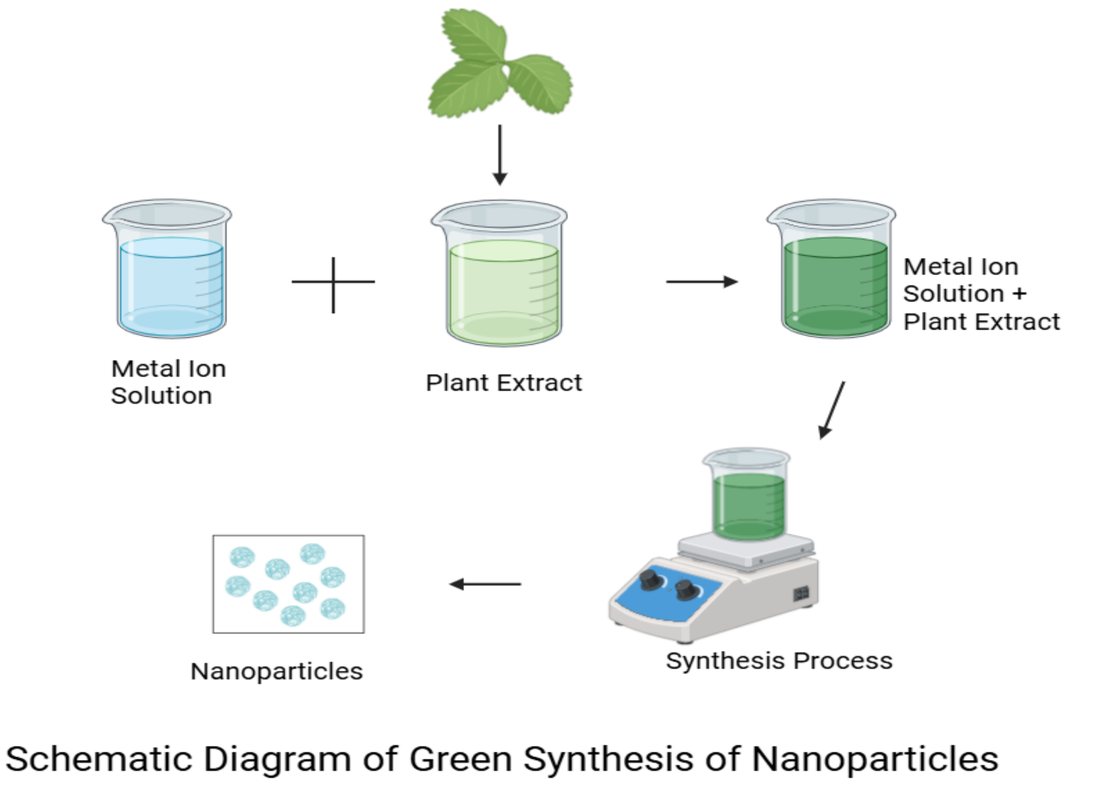
Priming, which relies on controlling moisture and drying to produce rapid germination, is the most viable rejuvenation strategy for encouraging germination of seed and development of plants by increasing sufficient metabolic activity for germination. As a result, germination rate, measurements of root/shoot extension, photosynthetic efficiency, seedling strength and growth-related indices may all increase. There is a lot of promise for nanoscience to guarantee agricultural output. Assessments indicate that the use of nanoparticles can affect both the germination of seeds and the plant growth and development. Recently, there has been interest in using green synthetic nanoparticles made from plant or microbial extraction as nano-priming agents because of their environmental synthesis that is easier to understand and less harmful than alternatives that are produced chemically [12,13]. This method is still largely experimental, as only a few discoveries have been made so far. More research is needed to better understand and unlock its full potential. So far, only limited studies have looked into how green-synthesized nanoparticles and polymer-based nanocomposites impact seed germination.

The creation of eco-friendly methods for synthesising nanoscale materials has become a significant focus for material scientists in current years. The green synthesis of nanoparticles, particularly through the use of extracts from various plants, is an emerging trend recognized for its simplicity, cost-effectiveness, and non-toxic nature within the field of green chemistry [14,15]. Nanotechnology has enhanced the human standard of living by addressing various everyday issues, including contributions to energy sufficiency, climate change, and advancements in the beauty, textile, and health industries, particularly in the treatment of severe diseases such as cancer and Alzheimer's.[16]

Synthetic approach	TMONPs	Application	Reference
Co-precipitation	ZnO NPs	Removal of Malachite green oxalate (MGO) and hexavalent Chromium (Cr)	Kumar et al. (2013)
Green synthesis	NiO NPs using Ocimum sanctum	Adsorption of dye and other pollutants	Pandian et al. (2015)
Ball-milling method	Goethite nanocrystalline powder	Adsorption of Cd(II)	khezami et al. (2016)
Hydrothermal	CuO and NiO nanoflakes	Removal of Malachite green oxalate (MGO) and methyl orange (MO)	Kumar et al. (2017)
Precipitation method	Copper- doped ZnO NPs	Humidity sensing device	Thiwawong et al. (2018)
Sol-gel method	γ- Al_2O_3 NPs	Wastewater treatment (removal of Pb(II) and Cd(II))	Tabesh et al. (2018)
Microwave irradiation	γ-Fe2O3 NPs	Adsorption of MO dye	Roy et al. (2020)
Green synthesis	ZrO_2 NPs using the pericarp extract of Sapindus mukorossi	Adsorption of Methylene blue (MB) dye	Alagarsamy et al. (2021)

The objective of the study was to study the effect of the plant extract in agriculture field. The crystal structure and surface morphology of bio-mediated ZnO &NiO NPs were analysed using different techniques (XRD, FTIR,).The significant characterisation results led us to investigate their biological potential on the growth of pea plant.

This study presents the synthesis of zinc and nickel oxide nanoparticles using plant extract utilising liquid and powdered extracts from *Morus Alba* leaves and *Citrus X Sinesis* peel. The green synthesis of ZnO &NiO nanoparticles presents environmentally friendly characteristics and a range of agricultural applications. The metabolites function as oxidizing, reducing, and capping agents present in the aqueous plant extract in the synthesis of biogenic ZnO & NiO nanoparticles.



In this research aqueous and powdered plant extract, nickel acetate tetrahydrate and zinc acetate dihydrate were used as precursors to synthesize ZNPs & NNPs. The structural properties of synthesized ZNPs & NNPs have been confirmed through PXRD, FTIR, and zeta potential analysis.

CHAPTER 2

MATERIALS AND METHODS

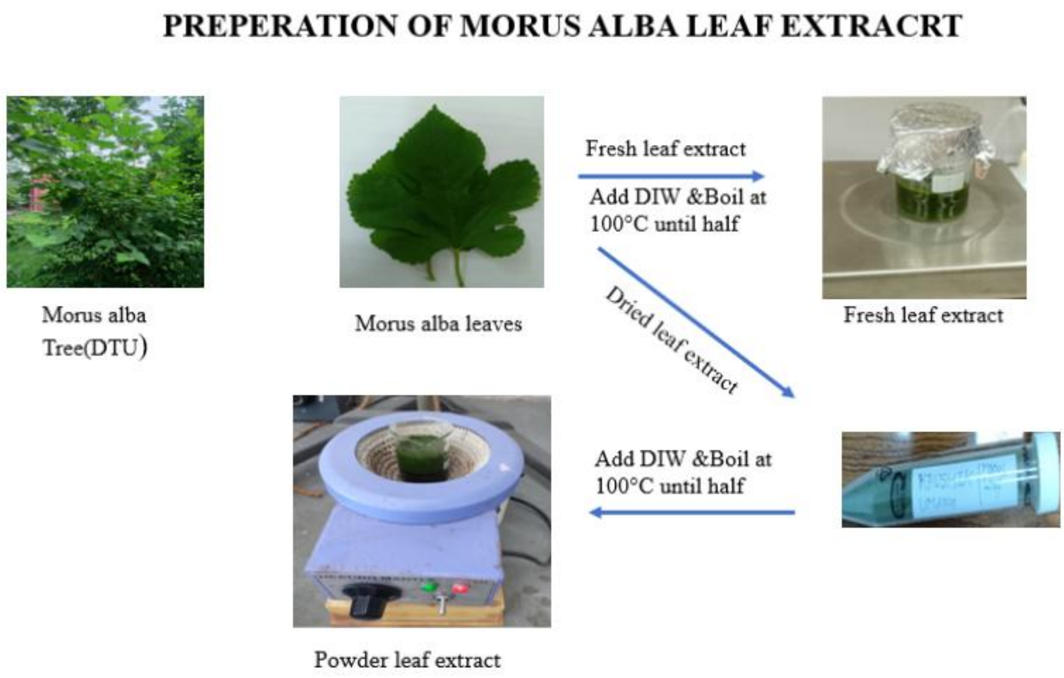
2.1 MATERIALS USED

Zinc Acetate Dihydrate (Zn $(CH_3COO)_2$,$2H_2O$), Sodium hydroxide (NaOH) of purity more than ≥ 99 % were procured from MERCK, Germany, Nickel Acetate Tetrahydrate (Ni $(CH_3COO)_2{\cdot}4H_2O$) was purchased from CDH chemicals. All the experiments were conducted using deionized (DI) water. *Citrus x sinensis* was purchased from market near DTU campus while fresh *Morus alba* leaves were collected from the Delhi Technological University campus.

2.2 METHODOLOGY

2.2.1 Preparation of *Morus Alba* plant extract

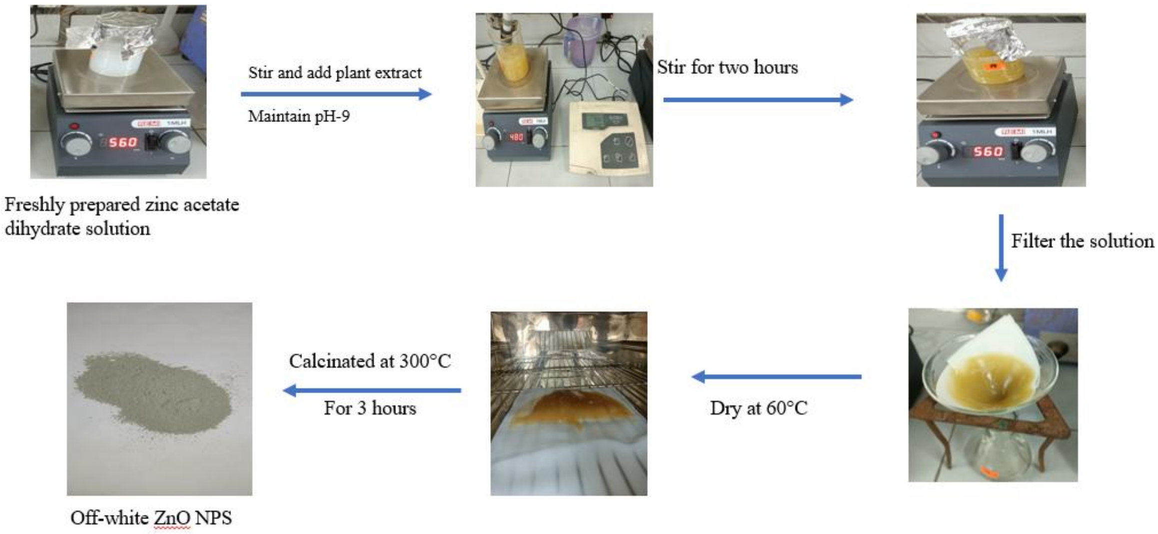
Morus Alba leaves were firstly cut into small pieces and then cleansed using distilled water. The cleaned leaves were dried in oven at 60°C for 24 hrs. Afterwards, dried leaves were grinded using mortar and pestle into fine powder and then stored in dry conditions. Morus Alba extract was prepared by adding 1.5 g of leaves powder into 30 mLof DI water and solution was stirred at 100°C for 30 min . The resulting solution was allowed to cool at room temperature. Lastly , the solution was filtered & filtrate was used as capping and reducing agent during the synthesis of ZnO NPs. Also for liquid plant extract , the leaves dipped in distilled water were boiled at 100°C on a heating plate until its volume decrease to half. Then the solution was filtered and filtrate was used in the synthesis of Zinc oxide NPs



2.2.2 Green Synthesis of Zinc Oxide Nanoparticles (ZnO NPs)

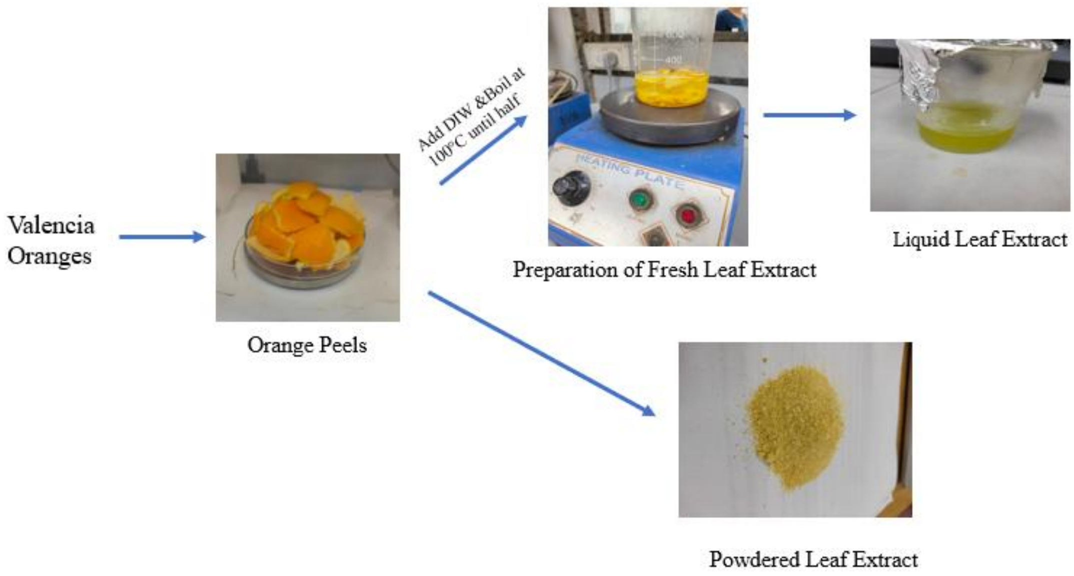
ZnO NPs were synthesised using co-precipitation method . Firstly, 2.1949 g $Zn(CH_3COO)_2.2H_2O$ was dissolved in 100 ml of DI water followed by dropwise addition of 10 ml morus leaf extract under constant stirring for 30 minutes. Then the pH of the reaction mixture was adjusted to 9 using 1M NaOH solution and the resultant solution was then further agitated for 2 hours. The obtained light pale -coloured precipitate was filtered, rinsed with a 50:50 solution of ethanol and water and then subjected to thermal drying in oven at 60 °C . Later, the precipitate thus obtained was sintered at 300 °C for 3 hours to get pale Morus Alba mediated ZnO NPs (MA-ZnO NPs).

SYNTHESIS OF ZnO NANOPARTICLES



2.2.3 Preparation of Citrus x Sinesis plant extract

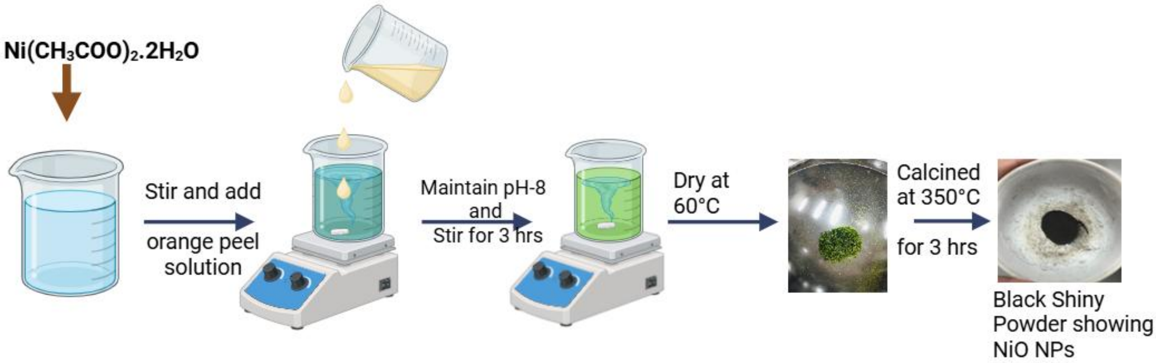
Valencia Oranges was washed with DI water. Orange Peels were dried in oven at 60°C for 24 hours and then grinded using grinder and stored in dry conditions. Plant extract was obtained by adding 1.5g of powder of orange peel into 50 mL DI water and solution was heated and stirred at 100°C for 30 min and the orange peel solution was allowed to cool down at room. Lastly , the solution was filtered and filtrate was used as reducing and capping agent during the synthesis of NiO NPs.Also, for liquid plant extract ,Orange peels dipped in distilled water was boiled at 100°C on heating plate until its volume decreases to half.Then the solution was filtered and filtrate used for the synthesis of Nickel oxide NPs



PREPERATION OF ORANGE PEEL EXTRACRT

2.2.4 Green Synthesis of Nickel Oxide Nanoparticles (NiO NPs)

NiO were synthesized using co-precipitation method. Firstly, 2.488g of ($Ni(CH_3COO)_2 \cdot 4H_2O$) was dissolved in 100 mL of DI water followed by dropwise addition of 10 mL orange peel extract under constant stirring for 20 minutes. The pH of reaction mixture was adjusted to 8 using 1M NaOH. The resultant solution was then further left undisturbed for continuous stirring of 4 hours. Obtained green coloured precipitate was filtered ,rinsed with 50:50 solution of ethanol and water and then kept in oven for thermal drying at 60°C. Later , the precipitate obtained was calcined at 300°C for 3 hours to get black coloured Citrus X Sinesis mediated NiO NPs (CS-NiO NPs).



Green Synthesis of NiO Nanoparticles

2.3 CHARACTERIZATION TECHNIQUES

2.3.1 Powder X-Ray Diffraction Analysis [PXRD]

PXRD is a technique used to determine the crystal lattice of powdered material. Figure 2.3 shows a typical Digital X-ray diffractometer. Sealed tubes, synchrotron radiation sources, and rotating anodes are usually used to generate X-rays. Material like as metals, ceramics, polymer, and semiconductors can be investigated using XRD analysis [24-29]. The technique can be used to identify unknown materials, characterize new materials, and monitor the quality of materials during manufacturing [30]. In XRD analysis, crystals diffract X-rays in a typical fashion, permitting an analysis of their structure. Several macro- and microstructural features of samples are can be obtained from, including:

• **Peak Position:** Curves analysis of the phase structure, chemical composition, macro stresses, and lattice parameters is provided.

• **Peak Shape:** Contributes to sample broadening (micro strains and crystallite size

$$D = 0.94\ \lambda / \beta \cos \theta \qquad (2)$$

Here, D is the avg. crystallinity ,

Å is wavelength,

FWHM is β (radian) and

the degree of diffraction indicated by θ.

Figure 2.1 Digital X-Ray Diffractometer.

2.3.2 Fourier Transform Infrared Spectroscopy [FTIR]

Fig. 2.2 Digital FTIR Spectrophotometer.

The FTIR analysis is a type of analytical technique that uses infrared radiation to identify and quantify a sample's chemical composition. Figure 2.4 shows a Digital FTIR Spectrophotometer. FTIR analysis measures the interaction between a beam of infrared light and a sample. In addition to providing information about the samples' chemical composition, the spectrum also identifies the functional groups present. As a result, no two compounds produce similar IR spectra. In this way, an IR spectrum can be used as an identification fingerprint. Different kinds of materials can be qualitatively analysed using IR spectroscopy. IR region is usually categorized into three regions i.e., far (14000- 4000 cm $^{-1}$), mid (4000 - 400 cm $^{-1}$) & near (400 - 10 cm $^{-1}$).

2.3.3 Zeta Potential

Nanoparticles and liquids have electrostatic potential differences, which is measured by the zeta potential. Several factors effect the behaviour of NPs, such as their surface composition, pH and ionic strength of the surrounding solution, and other molecules and ions present. Figure 2.5 shows a typical Zeta Potential Analyzer.

Nanoparticles with a high zeta potential are typically more stable and less likely to aggregate or clump together. This is because the Same-charged particles repel each other electrostatically prevents them from coming into proximity. On the other hand, nanoparticles with a low zeta potential may be more prone to aggregation, which can reduce their effectiveness in certain applications. The magnitude and sign of the zeta potential can be measured using techniques which are electrophoresis and dynamic light scattering. Careful control of experimental variables such as temperature and stirring rate is important to obtain accurate and reproducible results.

Figure 2.3 Digital Zeta Potential Analyzer

CHAPTER 3

RESULTS AND DISCUSSION

3.1 CHARACTERIZATION OF NANOPARTICLES

The Powder X-ray diffraction (PXRD) results of ZnO and NiO are shown in figure 3.1 and figure3.2.

Figure 3.1 shows PXRD pattern result for zinc oxide where the peaks positioned at 2θ angles value of 31.66, 34.35, and 36.15 corresponds to hexagonal wurtzite structure corresponding to the reflection planes having hkl values as (100), (002), and (101) [31].

Figure 3.2 showing the XRD pattern for nickel oxide where broad reflections at 2θ value of 37.2, 43.3, and 62.9 assigned to hkl values of the reflection planes are (111), (200), and (220)
.

With the addition of plant extact into ZnO and NiO NPs lattice , we observed that there is slight change in peak intensity and peak position.

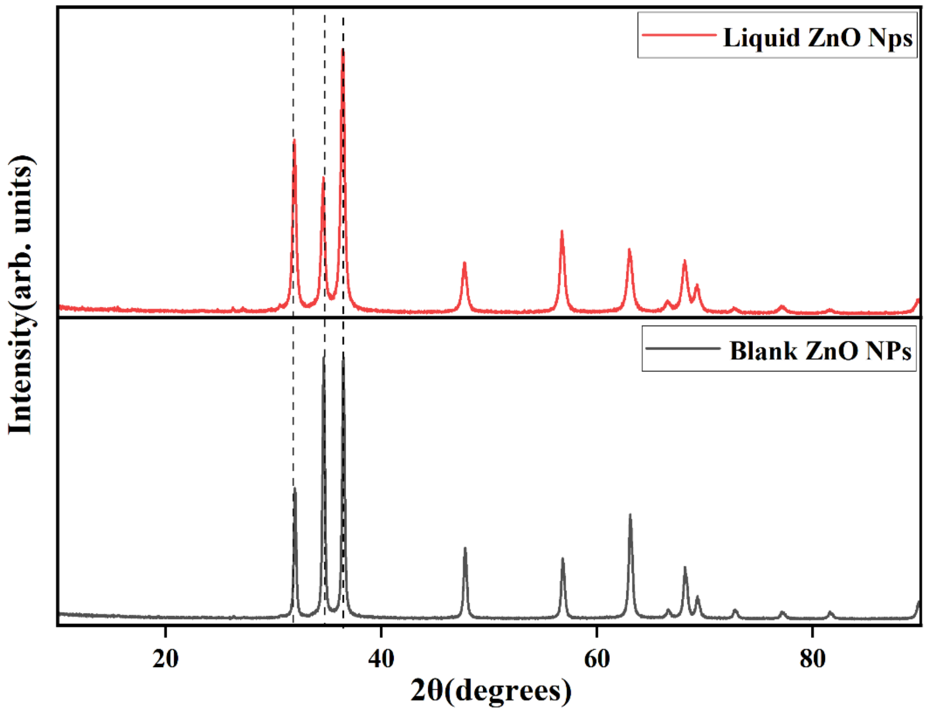


Figure 3.1 XRD pattern of green synthesized ZnO NPs

Metal Oxide	Samples	Peak Position(2Θ)	FWHM	Particle Size(nm)
Zinc Oxide	Chemically Synthesized	2482.23	0.64	13.66
	Green Synthesized	1838.65	0.43	20.18
Nickel Oxide	Chemically Synthesized	996.05	1.94	4.61
	Green Synthesized	1015.78	1.72	5.18

The crystallite size of synthesized ZnO & NiO NPs were calculated using Debye-Scherer which is given below as equation (2).

$$D = 0.94\ \lambda / \beta \cos \theta \qquad (2)$$

Here, D represents the average crystallite size, the wavelength is given in angstroms (Å), β denotes the full width at half maximum (FWHM) in radians, and θ corresponds to the diffraction angle. According to the Scherrer equation the average crystalline size (D) of the zinc oxide and NiO were calculated to be 15.60 and 17.1 nm, respectively.

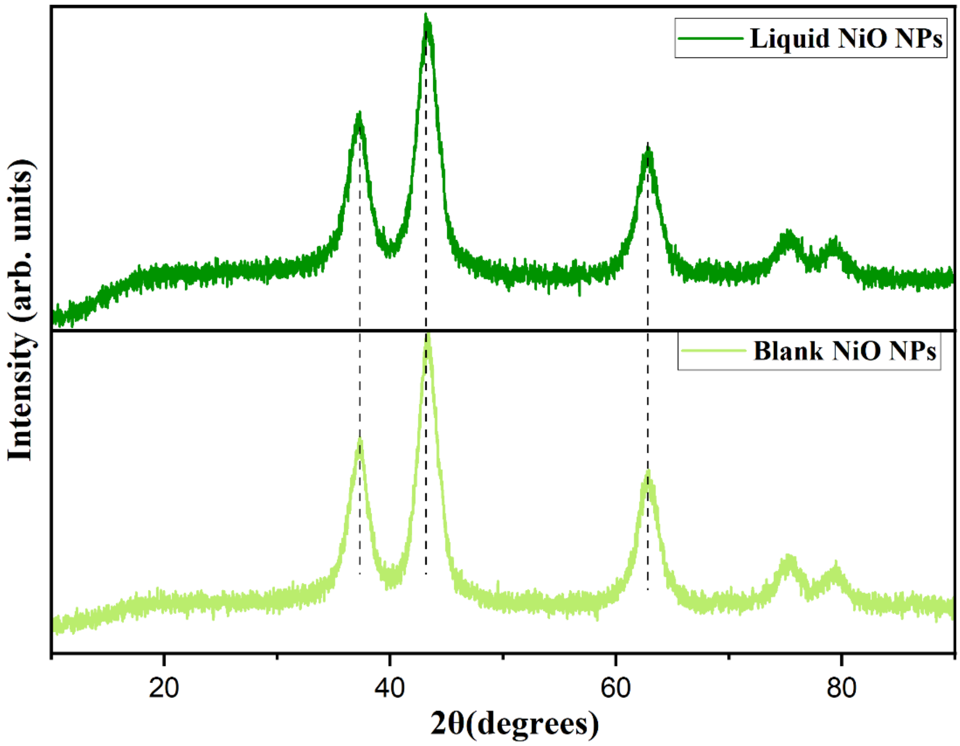


Figure 3.2 XRD pattern of green synthesized NiO NPs

FTIR spectrum of green synthesized ZnO NPs were given in figure 3.3 . As shown in figure 3.3 wide absorption measured at 3478 cm^{-1} is the vibrational stretching of hydroxyl group (O-H) of water present as moisture. There are peaks at 500 and 450 resulting from stretching vibrations in ZnO. The appearance of absorption bands between 1400cm^{-1} and 700 cm^{-1} is due to the presence of plant extract.

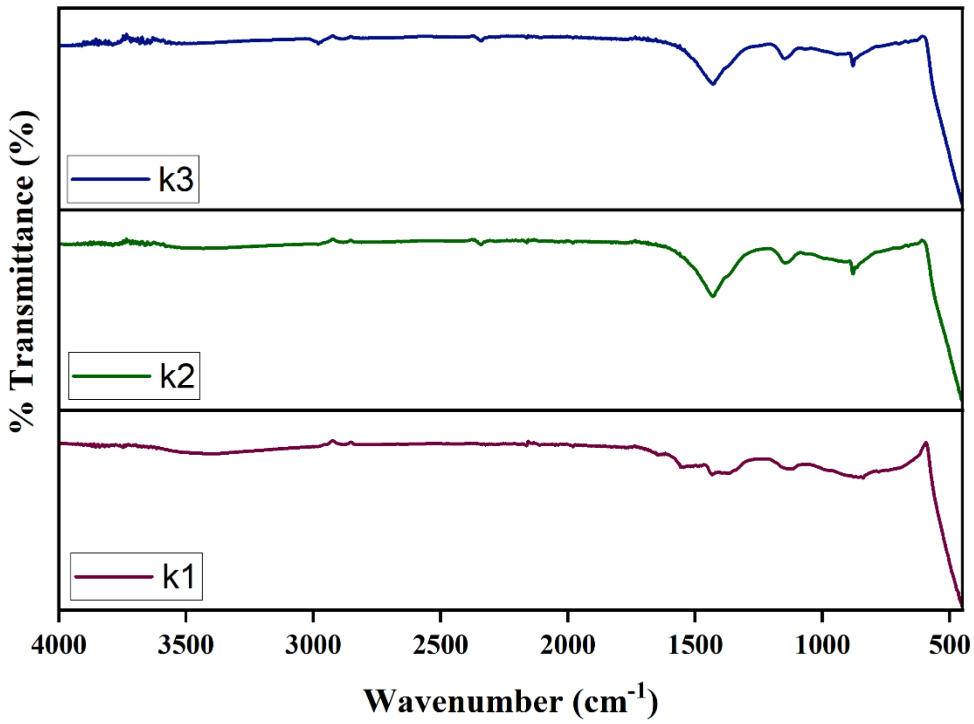


Figure 3.3 FTIR spectrum of ZnO nanoparticles

FTIR spectrum of green synthesized NiO NPs were given in figure 3.4 . As shown in figure 3.4 wide absorption measured at 3490 cm^{-1} is the vibrational stretching of hydroxyl group (OH) of water present as moisture. There are peaks at 500 and 490 cm-1 resulting from stretching vibrations in NiO. The appearance of absorption bands between 1700 and 1000 cm^{-1} is due to the presence plant extract.

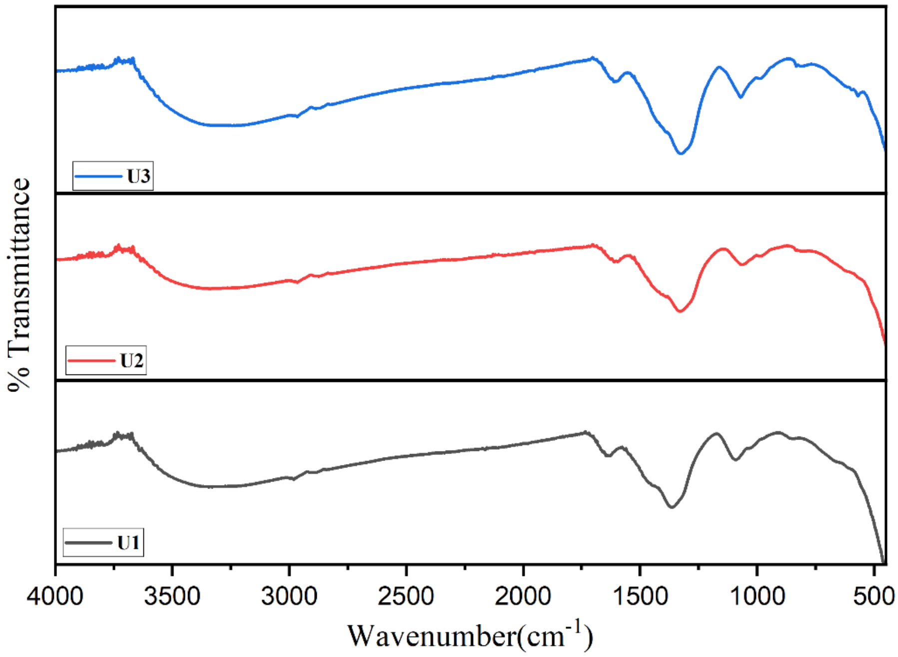


Figure 3.4 FTIR spectrum of NiO nanoparticles

Zeta Potential analysis was employed to determine the surface charge characteristics of synthesized ZnO NPs and this was found to be -26.4 mV, which implies that ZNP1 has a negative surface charge. Additionally, complexometric titration with standardized EDTA solution was employed to determine the zinc composition in synthesized ZNP1. The % of zinc in the MONPs was found to be 68%.

Chapter 4

APPLICATION

Zn and Ni serve as crucial micronutrients, contributing to physiological process including seed germination, plant development, increased crop productivity and resilience against environmental biotic and abiotic stresses. Recent studies have shown that seed priming with biologically synthesised ZnO and NiO nanoparticles has a positive impact on seedling growth and associated metabolic activities in several common staple crops such as pea, groundnut etc. Also, ZnO & NiO NPs offers agricultural applications, including improving plant growth, enhancing nutrient uptake, and exhibiting antimicrobial properties. Transition oxide-based NPs can facilitate uptake of crucial nutrients like zinc, phosphorus and nitrogen, which are crucial for plant growth and development.

Although Zinc deficiency in soils is becoming increasingly prevalent worldwide, excessive application also poses a significant threat to soil health and plant well-being .

"To study how ZnO & NiO nanoparticles influence seed sprouting and initial seedling development.", we germinate pea plant under laboratory conditions and investigated its germination with different samples (with powdered and liquid plant extract and blank ZnO and NiO). It was observed that seeds germination with green synthesized ZnO & NiO NPs showed higher growth as compared to blank ZnO & NiO. Table 1 &2 shows growth of pea plant with ZnO & NiO NPs. It was observed that there was more growth in plants which have biologically synthesized using dry and wet plant extract rather than nanoparticles synthesized without plant extract. We observed that in between biologically synthesized dry and wet NPs there was good growth in dry NPs. Plants with dry and wet synthesized NPs survived 20-25 days more than plants having NPs synthesized without plant extract. It was observed that seeds germinated with biologically synthesized NPs showing rich in biomolecules rather than plants without plant extract. Plant with Green-synthesized ZnO & NiO NPs generally promote better growth and stress resilience compared to other plants. They act not just as a micronutrient source but also enhance physiological processes through the bioactive compounds used in synthesis.

Table 1: Observation of the growth of Pea Plant using NiO NPs

Days	U1(normal soil(cm)	U2 (Ni without plant extract) (cm)	U3(Liquid plant extract) (cm)	U4(Powdered plant extract) (cm)
1	No Growth	No growth	No growth	No growth
2	No growth	No growth	**White embryo**	**White embryo**
3	No germination	No germination	0.5	0.5
4	**White embryo**	**White embryo**	1.0	1.0
5	0.2	0.2	1.4	1.5
6	0.8	0.9	1.9	2.2
7	1.4	1.6	2.5	2.8
8	1.9	2.1	3.0	3.4
9	2.8	2.8	3.6	4.1
10	3.0	3.0	4.2	4.8
11	3.6	3.8	4.9	6.0

Table 2: Observation of the growth of Pea Plant using ZnO NPs

Days	K1(normal soil(cm)	K2 (Zn without plant extract) (cm)	K3(Liquid plant extract) (cm)	K4(Powdered plant extract) (cm)
1	No growth	No growth	No growth	No growth
2	No growth	No growth	**White embryo**	**White embryo**
3	No germination	No germination	0.5	0.5
4	**White embryo**	**White embryo**	1.0	1.0
5	0.2	0.2	1.4	1.5
6	0.8	0.9	1.9	2.2
7	1.4	1.6	2.5	2.8
8	1.9	2.1	3.0	3.4
9	2.8	2.8	3.6	4.1
10	3.0	3.0	4.2	4.8
11	3.6	3.8	4.9	6.0

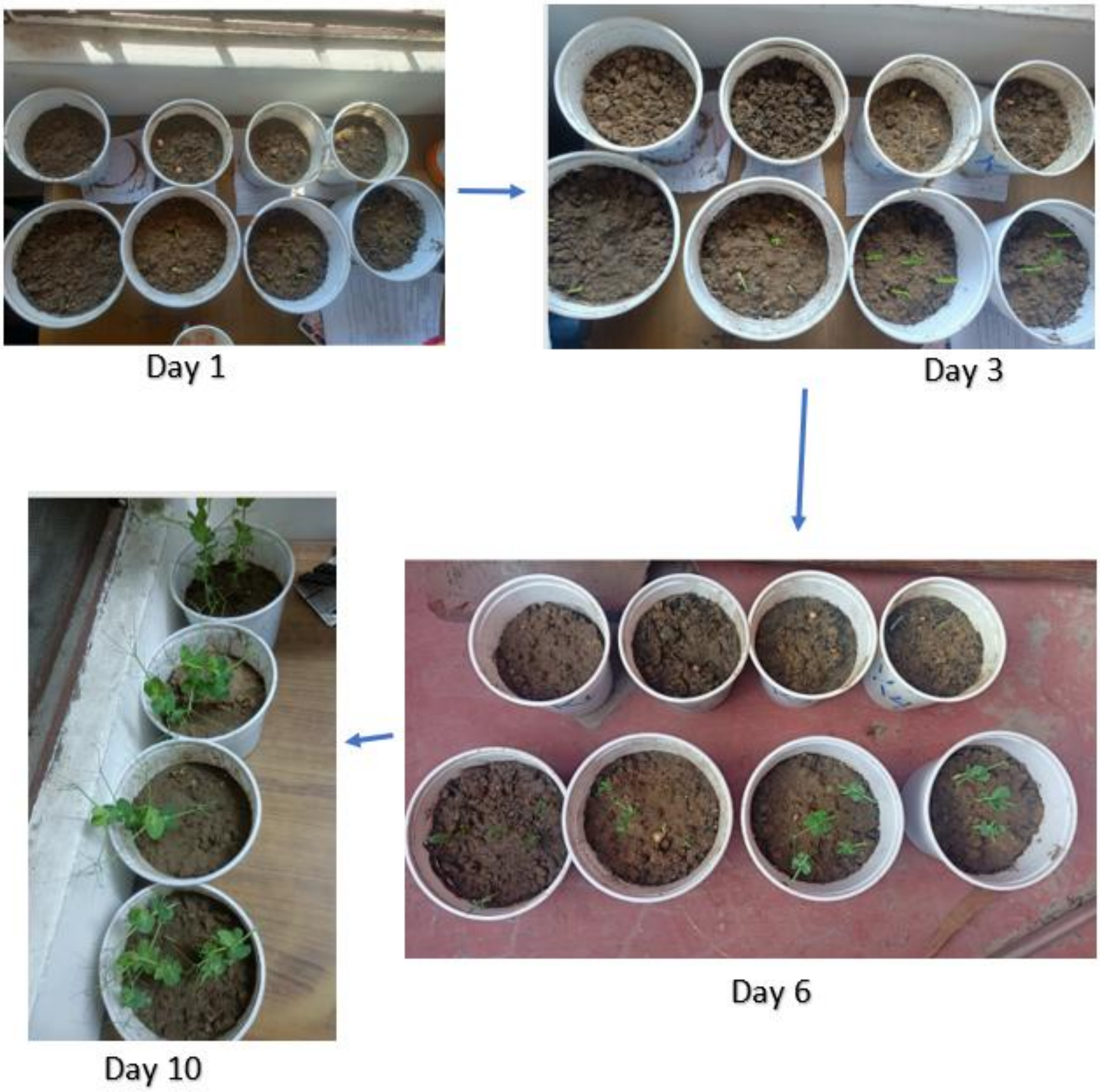


Figure 4.1 Plant Growth over several days

Green-Synthesized Transition oxide-based NPs vs Blank in Pea Plants

Parameter	**Green Synthesized NPs treated Plant**	**Blank**
Germination Rate	Improved germination percentage due to enhanced enzyme activation	Normal germination rate
Root & Shoot Length	Significant increase (Zn aids cell division and elongation)	Shorter growth compared to treated
Chlorophyll content	Higher SPAD readings; Zn boosts chlorophyll synthesis	Baseline chlorophyll levels
Stress Resistance	Better drought/salinity tolerance; lower electrolyte leakage and higher proline	Lower micronutrients Absorption
Root Nodule Formation	Improved nodulation due to better root health and rhizobial interaction	Delayed Nodule Formation

Study has shown that ZnO & NiO NPs can stimulate root and shoot growth, leading to increased biomass and overall plant health. In pea plants, green-synthesized ZnO & NiO nanoparticles clearly improve, Early growth stages, Nutrient assimilation, Chlorophyll content, Root nodulation and nitrogen fixation as compared to the blank treated plants.

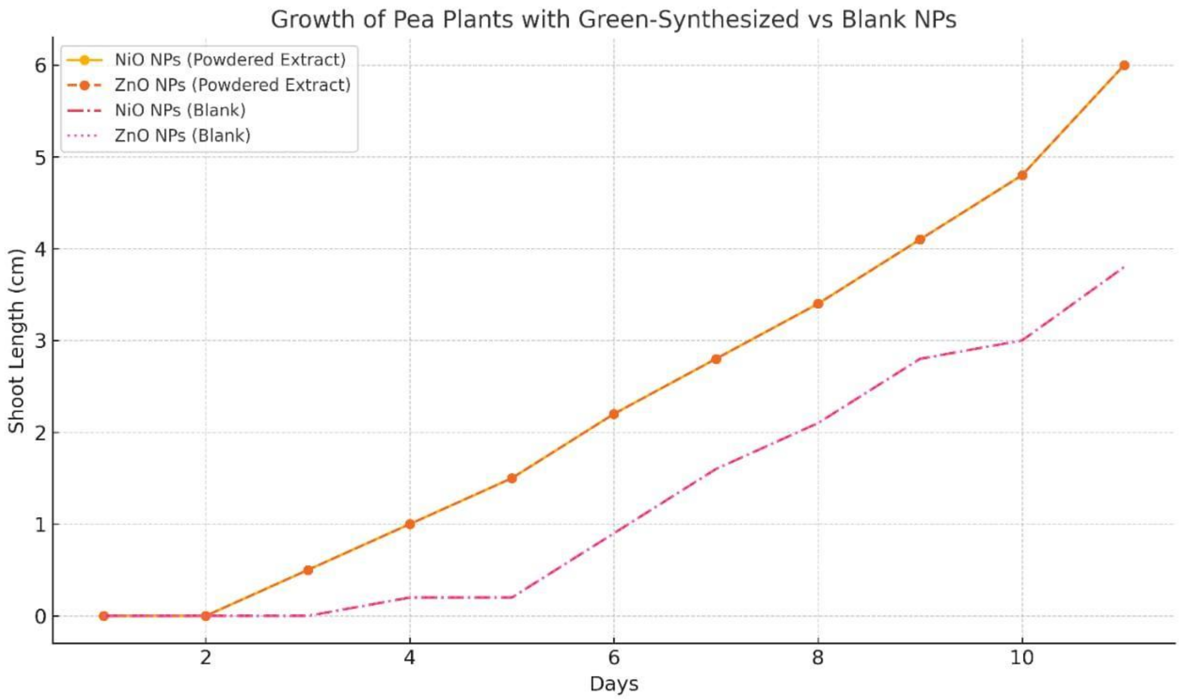


Figure 4.2 Graph showing growth of pea plant

CHAPTER 5

CONCLUSIONS AND FUTURE PROSPECTS

4.1 CONCLUSIONS

The present study reports "Green synthesis and characterization of zinc oxide and nickel oxide nanoparticles using *Morus alba* and *Citrus x Sinesis* plant extract" for agricultural application (Growth of pea plant). The synthesized nanoparticles were characterized using PXRD pattern, FTIR and Zeta Potential. From PXRD pattern it was confirmed with the addition of plant extract the average crystal size decrease which indicate the crystallinity of synthesized nanoparticles. From the FTIR it was confirmed that the sample is having a peak of CO group due to the presence of plant extract. The Environmental considerations and phytochemicals present in the plant make it efficient for synthesis processes, since it doesn't pollute and is less hazardous than chemical methods. In order to synthesize NiO and ZnO nanoparticles, a green approach was adopted. Present work introduces an innovative method that employs the *Morus Alba* and *Citrus x Sinesis* plant extract for the agriculture application i.e. the growth of pea plant . Agricultural application of NPs was investigated using different soil samples having nanoparticles and without nanoparticles on the growth of pea plant. It was observed that the pea plant shows fast growth using the green synthesized nanoparticles instead of blank nickel and zinc oxide nanoparticles. It was observed that the soil with green synthesized nanoparticles shows white embryo within 3 days while soil with chemical synthesized nanoparticles shows white embryo within 4 days. So, it concludes that the synthesized nanoparticles shows efficiency towards the faster growth of pea plant and the nanoparticles synthesized from the powdered plant extract shows fastest growth than nanoparticles synthesized from liquid plant extract.

4.2 FUTURE PROSPECTS

Use of plant-based methods to synthesize nanoparticles offers cleaner, more sustainable approach compared to traditional chemical processes. In our research, Nickel oxide (NiO) and Zinc oxide (ZnO) nano-sized particles were synthesized using plant extract, following the principles of green chemistry. These eco-friendly nanoparticles show great promise in agricultural applications, particularly in promoting healthy plant growth.

Zinc plays a vital role in plant development, especially in enzyme activity and chlorophyll production. When delivered in nanoparticle form, ZnO can enhance nutrient absorption and improve photosynthesis more effectively than conventional zinc fertilizers. Similarly, although nickel is required in smaller amounts, it is essential for nitrogen metabolism in plants. NiO nanoparticles have the potential to support seed germination and improve stress tolerance by boosting key physiological functions.

In the future, these nanoparticles could be used in Nano fertilizers or protective treatments to improve crop yields in a more sustainable way. As research advances, they may play an important role in reducing chemical inputs and supporting precision agriculture.

CHAPTER 6

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CHAPTER 7

CONFERENCE ATTENDED

Presented our research work in the Two-Day Symposium on "**Green Chemistry: Present and Future**" under the Organic Chemistry Series (OCS-2025) held on 13th–14th May, 2025 at Netaji Subhas University of Technology, New Delhi.

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