

**A REVIEW ON GREEN SYNTHESIS OF ZINC OXIDE
NANOPARTICLE USING ALOVERA EXTRACT**

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ABSTRACT

The present review focuses on the green synthesis of Zinc Oxide nanoparticles (ZnO-NPs) using Aloe vera leaf extract. It also discusses their potential pharmaceutical, cosmetic, and biomedical applications. Nanotechnology has gained significant importance due to the unique physicochemical properties of nanoparticles, such as high surface area, enhanced reactivity, antimicrobial activity, and UV protection ability. ZnO nanoparticles are widely used in sunscreens, wound healing products, drug delivery systems, and antimicrobial formulations because of their excellent antibacterial, antioxidant, anti-inflammatory, and photocatalytic properties. Conventional synthesis methods involve toxic chemicals and high energy consumption. In contrast, green synthesis using plant extracts offers an eco-friendly, economical, and safe alternative. Aloe vera contains bioactive phytochemicals, including flavonoids,

phenolic compounds, polysaccharides, and proteins. These compounds act as natural reducing and stabilizing agents during nanoparticle synthesis. The synthesized ZnO nanoparticles were characterized using UV-Visible spectroscopy, XRD, FTIR, and SEM analysis to determine their optical, crystalline, and morphological properties. The study also highlights the strong UV-blocking ability of ZnO nanoparticles, making them suitable for sunscreen and cosmetic formulations. Overall, green synthesized ZnO nanoparticles exhibit promising applications in

pharmaceutical, biomedical, environmental, and cosmetic fields due to their stability, biocompatibility, and environmentally friendly nature.

KEYWORDS: Green Synthesis, Zinc Oxide Nanoparticles, Aloe vera Extract, Phytochemicals, UV Blocking Property, Characterization.

INTRODUCTION

Nanotechnology is an emerging field of science that deals with materials having particle sizes in the nanometer range, generally less than 100 nm. Nanoparticles exhibit unique physical, chemical, optical, electronic, and biological properties because of their extremely small size and high surface area to volume ratio. Due to these special properties, nanotechnology has found wide applications in pharmaceuticals, medicine, cosmetics, electronics, agriculture, food industry, and environmental science.

Among various metal oxide nanoparticles, Zinc Oxide nanoparticles (ZnO-NPs) have attracted significant attention because of their excellent antimicrobial, antioxidant, anti-inflammatory, UV-protective, wound healing, and photocatalytic properties. ZnO nanoparticles are widely used in pharmaceutical products, drug delivery systems, cosmetics, biomedical devices, food packaging, textile industries, and environmental remediation.

One of the most important applications of ZnO nanoparticles is in sunscreens and cosmetic products. ZnO nanoparticles are highly effective UV filters that protect the skin from harmful ultraviolet (UV-A and UV-B) radiation from sunlight. Unlike traditional sunscreen agents, ZnO nanoparticles provide transparent protection on the skin without leaving a thick white layer. Due to their nanosize, they spread easily on the skin and improve the cosmetic appearance of sunscreen formulations. Additionally, ZnO nanoparticles possess anti-inflammatory and antibacterial properties, making them useful in skin care creams, lotions, ointments, and acne treatment products. They are also considered safer and less irritating compared to many chemical sunscreen agents.

ZnO nanoparticles can be synthesized by different methods including chemical, physical, and biological methods. Common synthesis techniques include sol-gel method, precipitation method, hydrothermal method, ball milling, laser vaporization, and microemulsion methods. However, these conventional methods have several disadvantages such as high cost, requirement of sophisticated instruments, use of toxic chemicals, high energy consumption,

and environmental hazards. Moreover, chemical stabilizers and reducing agents used during synthesis may remain attached to nanoparticles and affect their biological safety and pharmaceutical applications.^[1]

To overcome these limitations, green synthesis or biological synthesis of nanoparticles has gained great importance in recent years. Green synthesis involves the use of plant extracts, microorganisms, or natural compounds for nanoparticle production. This method is eco-friendly, economical, simple, less toxic, and energy efficient. Plant extracts contain various phytochemicals such as flavonoids, alkaloids, tannins, phenolic compounds, proteins, and terpenoids which act as natural reducing and stabilizing agents during nanoparticle synthesis.

Several medicinal plants have been successfully used for the green synthesis of ZnO nanoparticles, including *Salvadora oleoides*, *Ocimum americanum*, *Boswellia ovalifoliolata*, and *Aloe vera*. Green synthesized ZnO nanoparticles have shown excellent antibacterial, antifungal, antioxidant, anticancer, and photocatalytic activities. These properties make them highly useful in pharmaceutical and biomedical research.

Zinc is an essential trace element required for various biological functions in the human body. It plays an important role in enzyme activation, protein synthesis, DNA synthesis, cell growth, immune system regulation, wound healing, hematopoiesis, and neurogenesis. Zinc is naturally present in tissues such as skin, muscles, bones, and brain. Due to these important biological functions, zinc-based nanoparticles are considered highly promising for therapeutic and pharmaceutical applications.^[1,10] *Aloe vera* is one of the most commonly used medicinal plants for green nanoparticle synthesis. It belongs to the family *Aloaceae* and is rich in vitamins, enzymes, amino acids, polysaccharides, flavonoids, phenolic compounds, and antioxidants. The gel present inside *Aloe vera* leaves contains various bioactive compounds that help in the reduction and stabilization of nanoparticles during synthesis.

Aloe vera has been traditionally used for the treatment of burns, wounds, skin infections, ulcers, diabetes, arthritis, inflammation, and digestive disorders. It also possesses antimicrobial, antioxidant, moisturizing, anti-aging, and skin-soothing properties. Because of these medicinal and cosmetic benefits, *Aloe vera*-mediated ZnO nanoparticles are highly suitable for applications in pharmaceutical creams, ointments, sunscreens, and cosmetic formulations.

The present study focuses on the green synthesis of Zinc Oxide nanoparticles using *Aloe vera*

extract and their characterization using different analytical techniques. The study aims to evaluate the physicochemical properties and potential pharmaceutical, antimicrobial, cosmetic, and sunscreen applications of the synthesized ZnO nanoparticles.^[10]

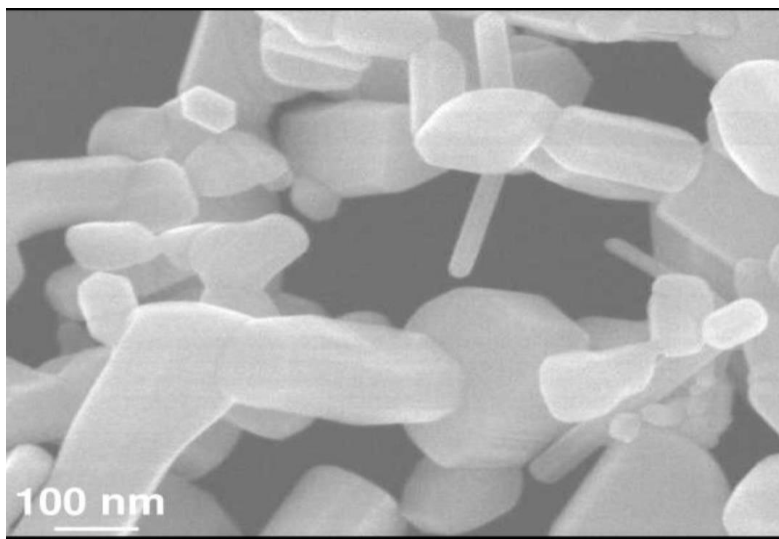


Fig. 1: Zinc Oxide nanoparticles.

Nanotechnology

Nanotechnology is a branch of science that deals with the study and application of materials having sizes between 1–100 nanometers (nm). One nanometer is one billionth of a meter. At this nanoscale, materials show unique physical, chemical, optical, and biological properties due to their large surface area to volume ratio.

Nanotechnology combines principles of physics, chemistry, biology, and engineering to develop advanced materials and devices with improved properties. Nanoparticles exhibit enhanced reactivity, strength, conductivity, antimicrobial activity, and UV protection compared to their bulk materials.

Nanoparticles can be synthesized by physical, chemical, and biological (green synthesis) methods. Green synthesis using plant extracts is considered eco-friendly, cost-effective, and less toxic.^[1]

Nanotechnology has wide applications in

- Pharmaceuticals and drug delivery
- Cosmetics and sunscreens
- Electronics and sensors

- Agriculture
- Food packaging
- Environmental protection

In the pharmaceutical and cosmetic industries, Zinc Oxide nanoparticles (ZnO-NPs) are widely used because of their antimicrobial, antioxidant, wound healing, and UV- blocking properties. ZnO nanoparticles are commonly used in sunscreens to protect the skin from harmful UV radiation.

Zinc Oxide Nanoparticles (ZnO-NPs)

Zinc Oxide nanoparticles (ZnO-NPs) are metal oxide nanoparticles with particle sizes generally ranging from 1–100 nm. They are widely used in nanotechnology because of their unique physical, chemical, optical, antimicrobial, and photocatalytic properties. Due to their nanosize and large surface area to volume ratio, ZnO nanoparticles show enhanced biological and pharmaceutical activities compared to bulk zinc oxide.

ZnO nanoparticles can be synthesized by physical, chemical, and biological (green synthesis) methods. Green synthesis using plant extracts is considered eco-friendly, economical, and less toxic because plant phytochemicals act as reducing and stabilizing agents during nanoparticle formation.^[13]

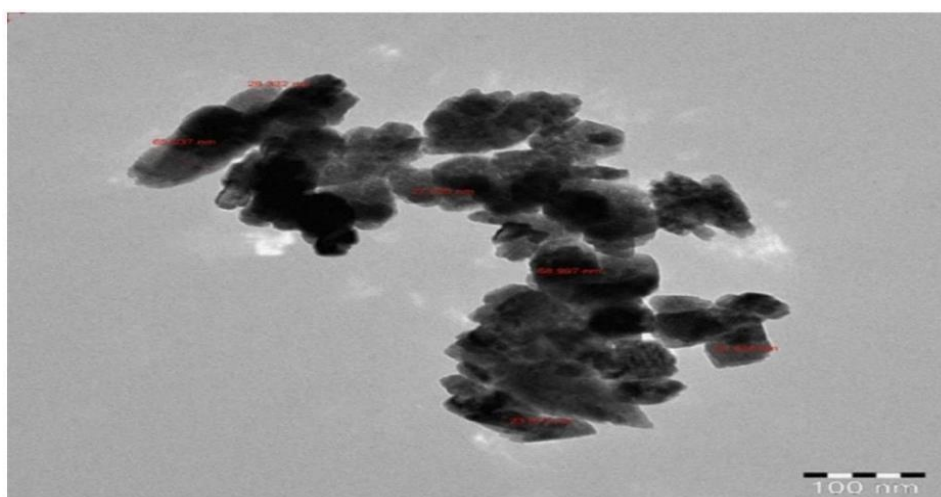


Fig. 2: Zinc Oxide nanoparticlaes.

Importance of Green Synthesis

Green synthesis of nanoparticles has emerged as an important and sustainable alternative to conventional chemical and physical synthesis methods. Traditional nanoparticle synthesis

techniques generally require toxic reducing agents, stabilizers, high temperature, high pressure, and sophisticated instruments, which may produce hazardous waste and environmental pollution. In contrast, green synthesis utilizes biological materials such as plant extracts, microorganisms, enzymes, and natural polymers for nanoparticle production. This method is environmentally friendly, energy efficient, non-toxic, and economically feasible. Plant extracts are particularly advantageous because they contain a wide variety of phytochemicals including flavonoids, alkaloids, tannins, terpenoids, proteins, sugars, and phenolic compounds that can naturally reduce metal ions into nanoparticles and stabilize them effectively. Green synthesized nanoparticles usually show improved biocompatibility and biological activity compared to chemically synthesized nanoparticles. Another major advantage of green synthesis is the elimination of harmful chemicals that may affect human health and the environment. In recent years, green nanotechnology has gained significant importance in pharmaceutical and biomedical research because it supports sustainable development while providing safe and effective nanomaterials for various applications including drug delivery, antimicrobial therapy, wound healing, cancer treatment, cosmetics, food packaging, and environmental protection.^[13]

ZnO nanoparticles possess several important properties such as

- Antibacterial activity
- Antifungal activity
- Antioxidant property
- Anti-inflammatory effect
- UV-blocking ability
- Photocatalytic activity
- High stability and biocompatibility

Because of these properties, ZnO nanoparticles have wide applications in pharmaceuticals, cosmetics, biomedical science, food packaging, agriculture, and environmental protection.

One of the major applications of ZnO nanoparticles is in sunscreens and cosmetic products. ZnO nanoparticles effectively absorb and scatter harmful UV-A and UV-B rays from sunlight, protecting the skin from sunburn and skin damage. Due to their nanosize, they form transparent sunscreen formulations without leaving a white layer on the skin.^[12]

In the pharmaceutical field, ZnO nanoparticles are used in

- Drug delivery systems
- Wound healing creams
- Antimicrobial ointments
- Anti-acne products
- Tissue engineering
- Cancer research

ZnO nanoparticles also show strong antimicrobial activity against various bacteria and fungi by damaging microbial cell membranes and generating reactive oxygen species (ROS).

Green synthesized ZnO nanoparticles using medicinal plants such as Aloe vera are gaining importance because they are safer, environmentally friendly, and suitable for biomedical applications. Aloe vera contains bioactive compounds like flavonoids, phenols, and polysaccharides that help in the synthesis and stabilization of ZnO nanoparticles.

Due to their excellent biological and physicochemical properties, Zinc Oxide nanoparticles have become one of the most important nanomaterials in modern pharmaceutical and cosmetic research.^[13,17]

Applications of Zinc Oxide Nanoparticles (ZnO-NPs)

Zinc Oxide Nanoparticles possess several remarkable properties that make them highly useful in scientific and industrial applications. One of the major advantages of ZnO nanoparticles is their strong antimicrobial activity against a wide range of bacteria, fungi, and other pathogenic microorganisms. This antimicrobial effect occurs due to the generation of reactive oxygen species and disruption of microbial cell membranes. ZnO nanoparticles also exhibit excellent UV absorption and scattering properties, making them highly useful in sunscreen and cosmetic formulations for protection against harmful ultraviolet radiation. Their high surface area and nanoscale size improve catalytic efficiency and biological interactions. ZnO nanoparticles are chemically stable, biocompatible, and relatively non-toxic at lower concentrations, which increases their suitability for biomedical applications. They also possess photocatalytic activity, enabling degradation of environmental pollutants and toxic dyes under light exposure. In addition, zinc oxide nanoparticles are cost-effective and can be synthesized easily through green methods using plant extracts. Their multifunctional properties make them valuable in pharmaceuticals, food packaging, biosensors, textiles, environmental remediation, electronics, agriculture, and biomedical engineering.^[1,13,17]

Zinc Oxide Nanoparticles are nanosized particles of zinc oxide having dimensions generally below 100 nm. Due to their unique properties such as:

- Large surface area
- High stability
- Antibacterial activity
- UV absorption ability
- Optical and catalytic properties

They are widely used in pharmaceutical, biomedical, cosmetic, agricultural, environmental, and industrial fields.

1. Pharmaceutical Applications

A) Drug Delivery System

ZnO nanoparticles are used as carriers for drug delivery because they can:

- Improve drug stability
- Enhance targeted drug delivery
- Increase bioavailability
- Provide controlled and sustained release

Advantages

- Reduced side effects
- Better therapeutic efficiency
- Controlled release at target site

B) Antibacterial Activity

- ZnO nanoparticles show strong antibacterial activity against:
- Gram-positive bacteria
- Gram-negative bacteria

Applications

- Antibacterial creams
- Wound healing products
- Coating for medical devices
- Packaging materials

C) Antifungal Activity

- ZnO nanoparticles inhibit fungal growth by:
- Destroying fungal cell membranes
- Producing oxidative stress

Applications include

- Antifungal ointments
- Agricultural fungicides

D) Anticancer Activity

ZnO nanoparticles can selectively kill cancer cells due to:

- ROS generation
- Induction of apoptosis
- DNA damage in tumor cells

They are considered promising in targeted cancer therapy.

2. Cosmetic Applications

A) Sunscreens and UV Protection

- Why ZnO-NPs are used?
- Absorb ultraviolet (UV) radiation
- Reflect harmful UV rays
- Protect skin from damage

Advantages over normal ZnO

- Nano-sized ZnO:
- Appears transparent on skin
- Gives better spreadability
- Provides improved UV protection

B) Anti-aging and Skin Care Products

- Anti-aging creams
- Moisturizers
- Face packs

3. Environmental Applications

A) Water Purification

ZnO nanoparticles help remove:

- Toxic dyes
- Heavy metals
- Organic pollutants

4. Agricultural Applications

A) Nano-fertilizers

ZnO nanoparticles provide zinc micronutrients to plants.

- Improved plant growth
- Better seed germination
- Increased crop yield

5. Food Industry Applications

A) Food Packaging

- Prevent microbial growth
- Increase shelf life
- Maintain food quality

B) Food Preservation

Their antimicrobial property helps reduce food spoilage.

UV Blocking Property of Zinc Oxide Nanoparticles

One of the most significant properties of zinc oxide nanoparticles is their excellent ability to absorb and scatter ultraviolet radiation. ZnO nanoparticles possess a wide band gap and high exciton binding energy, which allow them to effectively block harmful UVA and UVB rays from reaching the skin. Unlike conventional bulk zinc oxide particles, nanoparticles provide superior UV protection while remaining transparent or less visible on the skin surface, improving cosmetic acceptability. Due to their nanoscale dimensions and increased surface area, ZnO nanoparticles show enhanced interaction with ultraviolet light and provide efficient broad-spectrum sun protection. This property has made them important ingredients in sunscreens, cosmetic creams, lotions, protective coatings, textile materials, and pharmaceutical skin care products. ZnO nanoparticles help prevent skin damage, premature aging, sunburn, and skin cancer caused by prolonged UV exposure. In addition to UV protection, their antioxidant and antimicrobial activities further improve their usefulness in

dermatological and cosmetic applications. The incorporation of green synthesized ZnO nanoparticles into sunscreen formulations is gaining popularity because they are considered safer and more environmentally friendly compared to some synthetic UV filters.^[4,13,17]

Literature Review

1. Agarwal et al. (2017)

This review comprehensively addresses the eco-friendly transition in nanotechnology, highlighting how biological alternatives mitigate the high energy demands, costly instruments, and toxic chemical constraints inherent to physical and chemical synthesis.

2. Sangeetha et al. (2011)

A foundational reference demonstrating the structural properties and optical transitions of ZnO nanoparticles utilizing *Aloe barbadensis* Miller leaf extracts, showcasing the successfully modified hexagonal crystal parameters.

3. Chaudhary et al. (2019)

Investigates the potential of exploiting *Aloe vera* peel extract rather than pure internal leaf gel, validating that outer plant matrices still hold rich phytochemical arrays capable of driving efficient synthesis.

4. Prakash et al. (2022)

Offers comparative insights directly contrasting the physical/optical outputs of ZnO nanoparticles achieved via standard aqueous leaf extracts of *Aloe vera* against basic chemical counterparts.

5. Vidya et al. (2013)

Synthesizes zinc oxide nanoparticles using *Calotropis gigantea*, testing the performance metrics of alternative succulent/milky plant systems.

6. Wu et al. (2024)

A crucial modern study focusing explicitly on *Aloe vera* leaf extract processing parameters to yield ZnO nanoparticles, followed by an in-depth baseline evaluation of both antimicrobial efficacy and free-radical antioxidant scavenging capabilities.

7. Dobrucka & Długaszewska (2016): Investigates bacterial inhibition patterns of green-synthesized metal oxides, highlighting how membrane degradation and oxidative stress

pathways neutralize targeted microbes.

8. Jamdagni et al. (2018): Broaden the antimicrobial spectrum by validating antifungal performance, verifying that biogenic zinc oxide effectively restricts pathogenic fungal development.

9. Rajiv et al. (2013): Utilizes the leaf extract of the weed *Parthenium hysterophorus* to fabricate biogenic nanomaterials, confirming that diverse wild weed species offer viable reducing chemistry.

10. Kumar et al. (2014): This text profiles a generic "green approach" for fabrication, detailing how biological entities substitute toxic industrial stabilizing and reducing agents to safely secure high-quality ZnO nanoparticles optimized for industrial and systemic applications.

11. Bhuyan et al. (2016): Focuses on standard synthesis, structural classification, and the foundational evaluation of the surface-active catalytic properties of fabricated zinc oxide nanoparticles.

12. Yusof et al. (2019): Explores antimicrobial potential from a different biological perspective by documenting the utility of microbes (microbial synthesis) to manufacture active ZnO nanoparticles.

13. Lee et al. (2019): Analyzes hybrid engineering approaches through TiO₂/ZnO composite nanofibers, monitoring their combined performance in tracking and inducing photocatalytic degradation.

14. Dar et al. (2021): Explores structural dynamics specifically using Aloe vera leaf gel complexes to form robust ZnO nanocomposites, emphasizing stabilization driven by natural mucilaginous compounds.

15. Rehman et al. (2025): Documents the contemporary evolution of utilizing Aloe vera as a green source to produce highly specific, functional nanoparticles, emphasizing structural purity.

16. Narendra et al. (2019): Details a systematic phyto-mediated study using the aqueous leaf extract of *Ocimum americanum* (American Basil), illustrating how traditional aromatic herbs

act as effective alternative capping configurations.

17. Sedefoglu (2023): Offers a concise, definitive exploration directly connecting the exact structural characterization profiles of green-synthesized zinc oxide nanoparticles to their real-world photocatalytic decomposition efficiency under light spectrums.

Plant Profile and Phytochemistry of Aloe vera

Plant Profile of Aloe vera

- Scientific name : Aloe vera (Aloe barbadensis Miller)
- Family : Aloaceae
- Kingdom : Plantae

Common Names

- Aloe vera
- Ghritkumari
- Kumari

Description

Aloe vera is a succulent medicinal plant with thick, fleshy green leaves containing transparent gel. It grows mainly in tropical and semi-tropical regions.



Fig. 3: Aloe vera Plant Leaves.

Morphological Features

Leaves: Thick, fleshy, green, and spiny at edges Stem: Very short stem

Roots: Fibrous root system Flowers: Yellow tubular flowers

Gel: Transparent mucilaginous gel inside leaves

Distribution

Aloe vera is widely cultivated in:

- India
- Africa
- Middle East
- Mediterranean regions

Uses of Aloe vera

- Wound healing
- Skin care
- Anti-inflammatory activity
- Antioxidant activity
- Antimicrobial activity

Phytochemistry of Aloe vera

Aloe vera is a medicinal plant rich in various bioactive phytochemical constituents responsible for its therapeutic and nanoparticle synthesizing properties. The plant contains important compounds such as flavonoids, phenolic compounds, tannins, saponins, anthraquinones, polysaccharides, vitamins, enzymes, amino acids, and proteins. Flavonoids and phenolic compounds act as strong antioxidants and play an important role in reducing metal ions during the green synthesis of zinc oxide nanoparticles. Polysaccharides such as acemannan and glucomannan contribute to stabilization and capping of nanoparticles by preventing aggregation. Anthraquinones like aloin and emodin possess antimicrobial, anti-inflammatory, and antifungal activities. Aloe vera also contains vitamins A, C, E, and B-complex, which provide antioxidant and skin-protective effects. Enzymes such as amylase, catalase, and lipase help in various biological and metabolic activities. The presence of amino acids and proteins further supports tissue repair and biological functions. Due to the abundance of these phytochemicals, Aloe vera acts as a natural reducing, stabilizing, and capping agent in the green synthesis of zinc oxide nanoparticles, making the synthesis process eco-friendly, safe, and cost-effective.^[2,6]

Major Phytochemical Constituents

1. Flavonoids

- Kaempferol
- Quercetin

2. Phenolic Compounds

- Phenols
- Tannins

3. Polysaccharides

- Acemannan
- Glucomannan

4. Saponins**5. Anthraquinones**

- Aloin
- Emodin

6. Vitamins

- Vitamin A
- Vitamin C
- Vitamin E
- Vitamin B12

7. Enzymes

- Amylase
- Catalase
- Lipase

AIM OF THE PROJECT

To synthesize Zinc Oxide Nanoparticles using Aloe vera leaf extract by an eco-friendly green synthesis method and to characterize the synthesized nanoparticles using various analytical techniques.

Objectives of the Project

1. To prepare aqueous extract of Aloe vera leaves.
2. To synthesize zinc oxide nanoparticles using zinc acetate and Aloe vera extract by green synthesis method.
3. To study the role of Aloe vera phytochemicals as reducing and stabilizing agents in nanoparticle formation.
4. To characterize the synthesized ZnO nanoparticles using
 - UV–Visible Spectroscopy
 - X-Ray Diffraction (XRD)
 - Fourier Transform Infrared Spectroscopy (FTIR)
 - Scanning Electron Microscopy (SEM)
5. To determine the particle size, shape, and crystalline nature of ZnO nanoparticles.
6. To evaluate the stability and morphology of synthesized nanoparticles.
7. To develop a simple, cost-effective, and environmentally friendly method for ZnO nanoparticle synthesis.
8. To explore the potential pharmaceutical, antimicrobial, and biomedical applications of ZnO nanoparticles.

Materials and Equipment Required Chemicals

1. Zinc acetate
2. Sodium hydroxide (NaOH)
3. Distilled water
4. Deionized water
5. Potassium bromide (KBr) for FTIR analysis

Plant Material

- Fresh Aloe vera leaves

Consumables

- Whatman filter paper
- Petri dishes
- Glass beakers
- Conical flask
- Measuring cylinder
- Pipettes
- Centrifuge tubes

- Mortar and pestle

Equipment Required

1. Electric blender
2. Magnetic stirrer with hot plate
3. Water bath
4. Oven
5. Centrifuge machine
6. UV–Visible Spectrophotometer
7. pH meter
8. Analytical balance

Plan of Work

The present work focuses on the green synthesis of Zinc Oxide Nanoparticles using Aloe vera leaf extract. The study involves preparation of plant extract, synthesis of zinc oxide nanoparticles, purification, drying, calcination, and characterization using various analytical techniques. The plant extract acts as a natural reducing and stabilizing agent, making the synthesis eco-friendly, cost-effective, and safe compared to chemical methods.^[2,4]

Procedure for Preparation of Aloe vera Extract

1. Collect fresh Aloe vera leaves from a healthy plant source.
2. Wash the leaves thoroughly with distilled water to remove dust and impurities.
3. Remove the outer green peel carefully.
4. Cut the inner gel or leaf material into small pieces.
5. Weigh about 100 g of plant material.
6. Grind the material using an electric blender.
7. Transfer the mixture into a 250 ml conical flask containing 100 ml distilled water.
8. Heat the mixture at 90°C for 1 hour with continuous stirring.
9. Cool the solution to room temperature.
10. Filter the extract using Whatman filter paper.
11. Collect and store the filtrate for nanoparticle synthesis.

Procedure for Green Synthesis of ZnO Nanoparticles

1. Prepare 0.2 M zinc acetate solution in 50 ml deionized water.
2. Stir the solution until complete dissolution occurs.

3. Add 10 ml Aloe vera extract dropwise into the zinc acetate solution.
4. Continue stirring using a magnetic stirrer for 10–15 minutes.
5. Add 2 M NaOH solution dropwise to adjust pH.
6. Observe formation of white precipitate indicating ZnO nanoparticle formation.
7. Continue stirring for uniform synthesis.
8. Centrifuge the solution to separate nanoparticles.
9. Wash the precipitate several times with distilled water.
10. Filter the purified precipitate.
11. Dry the material in an oven at 60°C.
12. Grind the dried product into fine powder using mortar and pestle.^[4]

Calcination Procedure

1. Transfer the dried nanoparticle powder into a petri dish or crucible.
2. Place the sample in a muffle furnace.
3. Heat at 300–400°C for about 2 hours.
4. Allow the sample to cool to room temperature.
5. Collect the final ZnO nanoparticle powder and store properly.^[18]

Characterization of ZnO Nanoparticles

The synthesized zinc oxide nanoparticles are characterized to confirm nanoparticle formation, determine particle size, morphology, crystallinity, and identify functional groups involved in synthesis. Different analytical techniques such as UV–Visible spectroscopy, X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy (SEM) are used for characterization studies.^[11]

UV–Visible Spectroscopy Procedure

1. Prepare nanoparticle suspension in distilled water.
2. Transfer the sample into a cuvette.
3. Record absorbance in the wavelength range of 300–600 nm.
4. Observe characteristic absorption peak for ZnO nanoparticles.^[2]

Principle

Zinc oxide nanoparticles possess excellent ultraviolet (UV) light absorbing and scattering properties. Due to their nanosized structure and wide band gap, ZnO nanoparticles can absorb harmful UVA and UVB radiations, making them useful in sunscreens and cosmetic

formulations.

Materials Required

- Synthesized ZnO nanoparticles
- Distilled water or ethanol
- UV–Visible spectrophotometer
- Quartz cuvette
- Magnetic stirrer
- Beaker
- Pipette
- Glass rod

Procedure

1. Take a known quantity of synthesized ZnO nanoparticles.
2. Disperse the nanoparticles in distilled water or ethanol to prepare a uniform suspension.
3. Stir the suspension using a magnetic stirrer for proper mixing.
4. Transfer the prepared sample into a clean quartz cuvette.
5. Set the UV–Visible spectrophotometer in the wavelength range of 200–400 nm.
6. Use distilled water or ethanol as blank solution.
7. Record the absorbance spectrum of the ZnO nanoparticle suspension.
8. Observe absorbance in the UV region, especially between: 280–320 nm (UVB region)
320–400 nm (UVA region)
9. Higher absorbance in these regions indicates strong UV blocking activity.
10. Compare the absorbance with control sample if required. Observation
 - ZnO nanoparticles show strong absorption in the ultraviolet region.
 - The nanoparticle suspension blocks or absorbs harmful UV rays effectively.
 - Increased absorbance indicates better UV protection property.

Evaluation Test of Zinc Oxide Nanoparticles by UV–Visible Spectroscopy -Principle

UV–Visible spectroscopy is used to confirm the formation and optical properties of zinc oxide nanoparticles. ZnO nanoparticles absorb ultraviolet radiation due to electronic transitions between the valence band and conduction band. The appearance of a characteristic absorption peak in the UV region confirms nanoparticle synthesis.^[13,17]

Procedure

1. Take a small quantity of synthesized ZnO nanoparticles.
2. Disperse the nanoparticles in distilled water or ethanol to prepare a homogeneous suspension.
3. Stir the solution properly using a magnetic stirrer.
4. Centrifuge if necessary to remove larger particles or impurities.
5. Fill a clean quartz cuvette with the prepared nanoparticle suspension.
6. Use distilled water or ethanol as blank solution.
7. Set the UV–Visible spectrophotometer in the wavelength range of 200–600 nm.
 $\lambda = 200\text{--}600\ \text{nm}$
8. Scan the sample and record the absorbance spectrum.
9. Observe the characteristic absorption peak of ZnO nanoparticles in the UV region.
10. Note the wavelength of maximum absorbance (λ_{max}).

OBSERVATION

- Formation of ZnO nanoparticles is indicated by a strong absorption peak in the UV region.
- Generally, ZnO nanoparticles show absorption around 240–380 nm depending on particle size and synthesis conditions.
- Increase in absorbance confirms nanoparticle formation and stability.

Advantages of UV–Visible Analysis

- Simple and rapid method
- Confirms nanoparticle formation
- Determines optical properties
- Useful for stability studies
- Non-destructive analytical technique

Expected Outcome

The synthesized Zinc Oxide Nanoparticles exhibited significant UV blocking activity due to their strong absorption in the UVA and UVB wavelength regions. Therefore, ZnO nanoparticles can be effectively used in sunscreen and cosmetic formulations for UV protection.

CONCLUSION

The present study successfully demonstrated the eco-friendly green synthesis of Zinc Oxide Nanoparticles using Aloe vera leaf extract as a natural reducing, stabilizing, and capping

agent. The synthesis process confirmed that plant-mediated nanoparticle production is an effective alternative to conventional chemical and physical methods, which often involve toxic chemicals, high energy consumption, expensive instruments, and environmental hazards. The green synthesis approach used in this study proved to be simple, economical, non-toxic, environmentally safe, and suitable for large-scale production of nanoparticles.

The phytochemical constituents present in Aloe vera, including flavonoids, phenolic compounds, polysaccharides, proteins, tannins, and other bioactive compounds, played a major role in the reduction of zinc ions (Zn^{2+}) into zinc oxide nanoparticles and also helped in stabilization of the formed nanoparticles. These phytochemicals prevented aggregation of nanoparticles and contributed to the formation of stable ZnO nanoparticles with relatively uniform particle size and morphology. Thus, the study confirmed the important role of plant phytochemicals in nanoparticle biosynthesis and stabilization.

The synthesized ZnO nanoparticles were characterized using different analytical techniques to evaluate their structural, optical, and morphological properties. UV–Visible spectroscopy confirmed nanoparticle formation by showing characteristic absorption peaks in the ultraviolet region, indicating the optical properties and nanoscale nature of ZnO particles. X-Ray Diffraction (XRD) analysis revealed the crystalline structure and purity of the synthesized nanoparticles. The diffraction peaks confirmed the successful formation of crystalline ZnO nanoparticles, and the average crystallite size was found to be within the nanoscale range. Fourier Transform Infrared Spectroscopy (FTIR) analysis identified the functional groups present on the nanoparticle surface and confirmed the involvement of Aloe vera phytochemicals in reduction and capping processes. Scanning Electron Microscopy (SEM) studies revealed the surface morphology, particle distribution, and shape of the synthesized nanoparticles, indicating the formation of nanosized particles with relatively uniform structure and minimal aggregation.

The synthesized zinc oxide nanoparticles exhibited excellent UV blocking properties due to their strong absorption in the UVA and UVB regions. This property makes ZnO nanoparticles highly suitable for applications in sunscreen formulations, cosmetic creams, UV-protective coatings, textile materials, and pharmaceutical products. Compared to bulk zinc oxide, ZnO nanoparticles provide better transparency, higher surface area, and improved UV absorption efficiency, making them highly beneficial in cosmetic and dermatological preparations.

The study further demonstrated that green synthesized ZnO nanoparticles are highly stable,

biocompatible, and less hazardous compared to chemically synthesized nanoparticles. The method requires less energy, fewer hazardous chemicals, and simpler laboratory procedures, making it suitable for research as well as industrial applications.

Overall, the findings of the study conclude that Aloe vera-mediated green synthesis is an efficient and reliable method for producing high-quality zinc oxide nanoparticles with desirable physicochemical and biological properties. The synthesized ZnO nanoparticles showed good crystallinity, nanoscale particle size, stability, and effective UV absorption characteristics, confirming their potential use in pharmaceutical, cosmetic, biomedical, agricultural, environmental, and industrial fields. The study highlights the growing importance of green nanotechnology in developing safe, sustainable, and multifunctional nanomaterials for future applications.

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