

## **A SHORT REVIEW ON THE SYNTHESIS OF ZINC OXIDE NANOPARTICLES USING PLANT ISOLATE AND ITS ANTIFUNGAL POTENTIAL**

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### **ABSTRACT**

Plant pathogenic fungi can be a serious hazard to agriculture worldwide, lowering crop production yields, causing health problems, and having a substantial negative economic impact. Various conventional management strategies are used to control fungal diseases before and after harvest. However, because of their shortcomings and negative impacts on the environment, the manufacture of plant extracts-based metal oxide nanoparticles (NPs) is a viable alternative to the conventional approach. The objective of the study was to use a green method to biosynthesize zinc oxide (ZnO) NPs from different plant components and evaluate the antimycotic activity of these bioinspired ZnONPs against a range of harmful fungi. Because of their small size and unique biological activity, ZnO NPs have garnered a lot of attention from researchers. A straightforward one-step synthesis of ZnONPs can be facilitated by the potentiality of various plant components to decrease and encapsulate biomolecules. The characteristics of ZnO NPs are effectively altered by temperature, pH, and reagent concentrations. Characteristics including morphology, structure, and content are determined

using a variety of analytical methods, including FT-IR, TEM, EDX, zeta potential, and UV-Vis, etc. The antifungal efficacy of NPs against a plant pathogenic fungus was assessed, and microscopic analysis revealed that it damaged the hyphae and spore of a fungus. Future goals embrace the creation of sustainable methods, a greater variety of biological uses, and safety guidelines for the responsible use of ZnONPs.

**Keywords:** *antifungal potentiality, biosynthesis, plant pathogenic fungus, ZnO NPs*

### **Introduction:**

Due to the recent rapid expansion in the world's population, raising agricultural production (70%-100%) is urgently needed to meet the demands of a persistently growing population (Ghosh et al., 2025). However, economically significant crops can suffer critical harm from plant-pathogenic fungi, reducing agricultural productivity worldwide. Food safety problems and significant pre- and postharvest losses are still prevalent in several developing nations, mainly as a consequence of fungal activity, including the generation of mycotoxin (Nxumalo et al., 2024). For instance, the pathogen *Botrytis* sp. causes gray mold, which causes large losses in crops including tomatoes, strawberries, and grapes. Blue mold rot, caused by *Penicillium* sp., damages crops including apples, pears, and citrus and causes significant financial losses during transport and storage. *Mucor* sp. is responsible for a considerable quantity of postharvest degradation caused by the soft rot of numerous vegetables and fruits (Luciano-Rosario et al., 2020; Nxumalo et al., 2024). The long-standing usage of synthetic fungicides is more costly to protect the crops from fungal diseases either before or after harvest. However, overutilization of them has led to increased drug resistance, contamination of the food chain, financial losses, prolonged persistence, residual toxicity, environmental pollution, and negative side effects like diarrhea, liver damage, nausea, elevated body temperature, and renal failure (Lushchak et al., 2018).

Nanotechnology advancements are believed to be able to fix and treat these issues through different kinds of conventional

methods; nevertheless, these technologies have several disadvantages and adverse effects on the environment. According to the literature review, the biosynthesized metal oxide nanoparticles (NPs) have demonstrated remarkable antifungal action against spore-forming plant-pathogenic fungi and effectively inhibit fungal growth, which could pave the way for sustainable agriculture henceforth (Ghojavand et al., 2020). Zinc oxide has drawn a lot of interest due to its potency as an antifungal agent among other nano metal oxides. The key motive for this efficacy is its distinct physicochemical characteristics, which include its capacity to fabricate reactive oxygen species (ROS) in cells, such as hydroxyl groups, hydrogen peroxide, and superoxide anions; release zinc ions; and interrelate with fungal cell membranes to disrupt cellular functions. The outside of the microorganism exposed to the ZnONPs directly correlates with the collection of ROS produced (Djearamane et al., 2022; Hernandez et al., 2024). Consequently, plant-based biosynthesis methodologies have been explored as viable substitutes. The presence of several phytochemicals, including amides, terpenoids, phenolic compounds, polysaccharides, polyphenols, and flavonoids, in plant extracts influences particle size, shape, and stability, making them both reducing and stabilizing agents. The process has several benefits, such as being non-toxic, economical, ecologically benign, and generating stable nanoparticles with improved characteristics (Alprol et al., 2023; Ashour et al., 2023; Alprol et al., 2024; Nxumalo et al., 2024).

Thus, the chapter intends to review the capability of environmentally friendly ZnO nanoparticles as a successful and sustainable antimycotic agent in agriculture. The chapter also discussed produced nanoparticles that were described using several methods, such as UV-Vis, zeta potential, FT-IR, SEM, TEM, XRD, etc. Finally, the antifungal characteristics of ZnO nanoparticles derived from plants and their activity against a few plant-pathogenic fungi were described.

### **Biosynthesized nano zinc oxide:**

Numerous investigations on the synthesis of various inorganic metallic oxides, along with TiO<sub>2</sub>, ZnO, and CuO, have been reported. ZnO has drawn the most attention among these

due to its inexpensive production costs, ease of synthesis, and safe handling. n-type semiconductormetal oxide that has significant antimicrobial qualities and a wide variety of nanostructures (Niser et al., 2019). Moreover, having a higher surface-to-volume ratio and diverse morphologies, ZnO nanoparticles can stop any microbial growth. As stated in studies, while subjected to UV light, zinc oxide nanoparticles can generate significant amounts of H<sub>2</sub>O<sub>2</sub>, which causes oxidative stress that is detrimental to fungal cells. Ultraviolet (UV) light may also be absorbed by ZnO, and its nanoform can exhibit antifungal properties by producing Zn<sup>2+</sup> ions in microbial conditions. This mechanism has a significant effect on the metabolism of amino acids and disturbs the fungal enzymatic systems (Ghosh et al., 2025). The thorough examination and understanding of materials and structures at the nanoscale, typically between 1-100 nm in diameter, is known as nano-characterization. Accurate characterization is pivotal for various scientific, commercial, and technological applications because the properties and behaviors of materials at this scale might differ significantly. This has been accomplished through the development of a variety of advanced tools and methods, together referred to as nano-characterization instrumentation, including Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction (XRD), transmission electron

| Plant                     | Plant parts used | Zn precursor  | Shape                        | Size (nm) | Causative agent             | Disease                                                    | Ref.               |
|---------------------------|------------------|---------------|------------------------------|-----------|-----------------------------|------------------------------------------------------------|--------------------|
| <i>Nigella sativa</i>     | Seed             | Zinc sulfate  | Wurtzite Hexagonal structure | -         | <i>Cercospora canescens</i> | Disease in mung bean plants ( <i>Cercospora</i> leaf spot) | Aftab et al., 2025 |
| <i>Trachyspermum ammi</i> | Seed             | Zinc sulphate | Hexagonal wurtzite structure | 15-20     | <i>Cercospora canescens</i> | Disease in mung bean plants ( <i>Cercospora</i> leaf spot) | Rafiq et al., 2022 |

|                             |            |                                 |                          |       |                                                                                       |                                                                                          |                                 |
|-----------------------------|------------|---------------------------------|--------------------------|-------|---------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------|
| <i>Terminalia bellerica</i> | Leaves     | -                               | Spherical to hexagonal   | 20-30 | <i>Alternaria brassicae</i>                                                           | Blight disease in <i>Brassica juncea</i>                                                 | Dhiman et al., 2021, 2022, 2023 |
| <i>Ocimum americanum</i>    | Leaves     | -                               | Wurtzite structure       | 45-50 | <i>Aspergillus niger</i>                                                              | Black mold, fruit rot                                                                    | Vidhya et al., 2020             |
| <i>Eucalyptus globules</i>  | Leaves     | Zinc nitrate (with hexahydrate) | Mostly spherical         | 52-70 | <i>Diplodia seriata</i> , <i>Alternaria mali</i> , and <i>Botryosphaeria dothidea</i> | Diseases in Apple Orchards                                                               | Ahmad et al., 2020              |
| <i>Syzygium aromaticum</i>  | Flower bud | Zinc nitrate hexahydrate        | Triangular and hexagonal | 30-40 | <i>Fusarium graminearum</i>                                                           | <i>Gibberella</i> ear rot diseases in cereals and <i>Fusarium</i> stalk rot, head blight | Lakshmeesha et al., 2019        |

microscopy (TEM), etc. (Mohammed et. al., 2024). The way through which zinc oxide nanoparticles (ZnONPs) interact with microorganisms is dependent on numerous points, including:

**Surface Area and Particle Size:** Because of their smaller size ZnONPs (10–50 nm) with larger surface area-to-volume ratio interact more with microbial cells.

**Shape & Morphology:** In general, spherical and rod-shaped ZnONPs work better than irregular ones.

**Surface Charge & Functionalization:** Cell disruption of fungi results from the greater interactions of positively charged ZnONPs with negatively charged fungal membranes.

**Concentration:** More reactive oxygen species (ROS) are produced at higher ZnONP concentrations, which boosts antifungal action.

Plant extracts contain a variety of active biomolecules that stabilize and decrease nanoparticles. Earlier investigation has revealed that synthesis has used several plant extracts,

such as *Azadirachta indica*, *Aloe vera*, *Vitex trifolia*, *Moringa oleifera*, and many more extracts that have been shown to exhibit antifungal action in ZnO nanoparticles made from them. Plant parts like flowers, leaves, roots, stems, seeds, fruits, barks, rhizomes, peels, and shells have been utilized in this process, demonstrating the adaptability and variety of green synthesis techniques (Verma et al., 2025).

### **Antifungal potency of plant-moderated ZnONPs:**

The antifungal capabilities of phytofabricated ZnONPs have attracted a lot of attention as a result of their increased bioactivity, eco-friendly synthesis, surface functionalization, surface activity, bigger area, size, shape, and structure. Since nano zinc oxide exhibits antifungal qualities, different kinds of fungal strains, *Penicillium* sp., *Fusarium* sp., *Colletotrichum* sp., *Aspergillus* sp., *Rhizoctonia* sp., and others, have been used to study its antifungal potential in vitro (Table 1). There is still much debate on the antimycotic mechanism of metallic oxide nanoparticles.

**Table1:** Antifungal Potentiality of Plant-Based ZnO nanoparticle against phytopathogenic fungi

However, the mechanisms of antifungal activity of ZnO (Figure 1) are as follows (Nisar et. al., 2019; Ghorbani et. al., 2022; Gharpure et. al., 2022):

**Creation of Reactive Oxygen Species (ROS):** Producing ROS (hydroxyl radicals, superoxide anions, and hydrogen peroxide) via ZnO NPs disrupts the normal operation of numerous intracellular organelles and causes cell damage.

**Disruption of Cell Membrane:** ZnO NPs may interact with the fungal cell membrane, enhancing its permeability, which induces the leakage of vital biomolecules and, ultimately, to the cell death.

**Inhibition of Enzymes, Proteins, and DNA:** ZnONPs can influence the function of intracellular organelles and damage all biomolecules, including proteins and DNA, in the fungal cell by causing oxidative stress. By disrupting the electron transfer chain and destroying cellular enzymes, nanostructures can also lead to fungal death.

**Release of zinc ions:** Fungal metabolism is disrupted by the gradual release of Zinc cations from the dissolution of nano ZnO on the cell membrane surface, affecting enzyme activity and cellular processes.

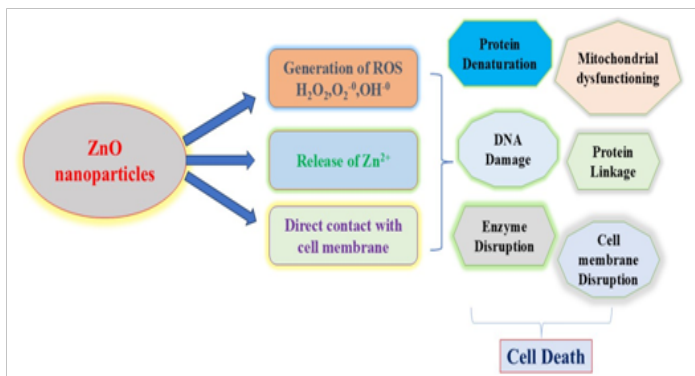


**Figure 1:** Mechanism of antifungal activity of ZnO NPs

### Future prospects:

The employment of bioinspired ZnO NPs in antifungal applications is gaining popularity because of its strong antimicrobial capabilities, biocompatibility, and environmentally benign manufacturing.

### Future studies can focus on:

- Enhancing the bioavailability and stability of ZnO NPs for usage in medicine and agriculture.
- Optimizing synthesis techniques to produce consistent ZnO NP size and shape, which has an immediate consequence antifungal efficacy.
- The occurrence of ecological friendly nano-fungicides to fight fungal diseases in crops.
- Toxicity issues related to ZnONP accumulation in living things.
- More investigation is mandatory to find out the long-term impacts on both the nature and human beings.

- ZnO nanoparticles may be more successful while incorporated with other antifungal agents.
- Cost-effective production requires the development of large-scale green synthesis techniques.

### **Conclusion:**

Green-synthesized ZnONPs hold promise as an efficient and environmentally friendly way to support biological activities. Their cost-effective, straightforward, and environmentally benign nature makes them a desirable substitute for conventional methods. A sustainable method of producing ZnO-NPs is offered by the usage of plant extractions as reducing and stabilizing representatives, which also removes the necessity for hazardous chemicals. These NPs showed great potential against plant-pathogenic fungi. The ZnONPs to preserve crops before and after harvest can satisfy the growing demand for food by managing new diseases and reducing waste in an environmentally conscious way. Thus, this strategy can greatly increase food security by reducing losses before and after harvest and securing the quality and safety of goods during storage and transit. Consequently, our results suggest that utilizing plant extracts to produce ZnO NPs offers a viable way to counteract resistant and developing plant diseases. Additionally, this strategy might be seen as a favorable way to deal with the current environmental problems.

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