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# Biosynthesis of Zinc Oxide Nanoparticles and Their Revolutionary Impacts on Agroindustry: Review

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***Abstract***

*Nanotechnology is a new approach of science which provides alternative tool in many fields including agriculture. This comprehensive review focuses on the biosynthesis and characterization of zinc oxide nanoparticles (ZnO NPs), highlighting their vast potential in agroindustry applications. Unlike traditional physical and chemical methods, which are often costly, time-consuming, and involve hazardous materials, this review explores the promising biological synthesis routes, offering a more sustainable and eco-friendly alternative for producing ZnO NPs. The biosynthesis of nanoparticles from the biological extracts like bacteria, fungi and plant parts (root, stem, leaf and seed) is very simple eco-friendly, and free from any harmful chemicals. Phytochemicals like phenolic, terpenoids, flavonoids and alkaloids act as stabilizing and reducing agents in the formation of NPs. Biosynthesis of NPs' confirmation is done by the UV-Visible spectroscopy, transmission electron microscopy (TEM), scanning electron microscope (SEM) with energy dispersive X-ray (EDX), and Fourier transform infrared spectroscopy (FTIR). UV-Visible gives strong spectra. TEM and SEM determine size and shape, EDX determines the purity of NPs and FTIR identifies the functional group of NPs. Zinc oxide nanoparticles (ZnO NPs) play a pivotal role in boosting plant growth and development, and their application as nano-fertilizers has revolutionized the agricultural landscape, offering a novel and effective approach to enhancing crop yields, improving nutrient uptake, and promoting sustainable farming practices. Due to presence of antimicrobial property, ZnO NPs exhibit strong activity against the plant pathogenic fungi and plant parasitic nematodes. ZnO NPs reduce the plant pathogens growth and can be used in management of plant disease. ZnO NPs increases plant growth and yield. ZnO NPs have important role as anticancer drug, antidiabetic, anti-inflammatory, dietary supplement agent, nano-fertilizers, nano-pesticides and nano-biosensors. Nano-biosensors are very advance technology which is used in plant pathogen detection. Biosynthesized ZnO NPs showed the antimicrobial activity and this property eliminates plant pathogens, so ZnO is employed in the plant disease management.*

**Keywords:** Zinc oxide nanoparticles, characterization, nano-fertilizers, nano-pesticides, biosensors

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## INTRODUCTION

Nowadays, nanotechnology has most significant value in textile industry, pharmaceutical and medical field. By the use of nanoscience, metal and metal oxide nanoparticles (NPs) are used in field of science and research institutes. Basically, nanotechnology itself is a big name as it has big impact in agriculture such as germination of seed, nano barcode of nanosensors, transfer of target gene, controlled release of agrochemicals, water management and delivery of hormone [1]. Because of especial chemical and physical qualities, nanoparticles have nice observation than the other macro-scale counterparts [2].

 

Nanoparticles have remarkable physicochemical qualities like as exceptional reactivity, conductivity and sensitivity and size of nanoparticles size range is less than 100 nm. Due to nano-scale dimension, small size of NPs increases the thermal conductivity, non-optical performance, large surface area and catalytic conductivity [3].

In various fields, nanomaterials have great impacts in different forms such as magnetic particles, quantum dots, metal non-metal, polymers and carbon nanotubes [4]. Nanoparticles are beneficial objects, in agriculture by enhancing pesticide delivery, nutrient supply, increased germination rate and photosynthetic rate, enhanced plant growth and development.

There are many traditional chemicals based fertilizers employed in agriculture but these chemical fertilizers are very harmful for the soil and crop; so by use of nanotechnology, fertilizers are produced at nanoscale such as carbon nano-onion [5] and chitosan NPs [6] which enhance the quality, quantity and crop growth.

ZnO NPs are synthesized from physical (colloidal, dispersion, vapor condensation and physical fragmentation, pulsed laser composition) [7], chemical (direct precipitation and micro-emulsion) [8] and biological (bacteria, fungi and plants) methods but physical and chemical methods are very harmful and toxic for the environments, whereas biological methods are eco-friendly, simple and free from toxicity.

Biosynthesized ZnO NPs have specific qualities such as bandwidth and high excitation binding energy and have various implementations, for example, antifungal, antidiabetic, antibacterial, wound healing, anti-inflammatory, optic quantities and as antioxidant [9].

Some researchers reported that various metal nanoparticles, for example, titanium dioxide, copper oxide and zinc oxide show the antiviral, antifungal and antifungal properties [10–12]. When nanoparticles are applied directly as foliar spray on the plant, it could be capable of acting in opposition of plant pathogens (bacteria, fungi and plant parasitic nematodes). Various metal oxide nanoparticles ZnO, $TiO_2$ and CuO NPs are employed in the management of plant diseases; among them, ZnO NPs inhibit the growth of plant pathogens *Fusarium graminirearum* [13], *Aspergillus flavus* and *F. oxysporum* [14].

Among physical and chemical methods, biological method is cost effective, simple, easy, ecofriendly and free from any chemical hazards, forming the biocompatible nanoparticles. Therefore, we will be discussing biosynthesis and its various applications, especially in management of plant diseases, in this study.

## ZINC OXIDE NANOPARTICLES

Nowadays, ZnO NPs are attracting the scientists' awareness due to its specific morphology, chemical and optical properties. Generally, metal oxides have large family but ZnO NPs are widely used in electronics, communication, cosmetics, environmental protection, medicinal industry and biology [15]. ZnO NPs have notable physical and optical qualities which enhance the agriculture production. In addition, ZnO NPs have many applications like biological sensing, biological labeling, gene delivery, nanomedicine and drug delivery, which are very important [16].

Zinc is a relevant nutrient element in living organism which has wide implementation as antimicrobial agents [17], in animals, plants, and also in humans. It is greatly affecting all the body tissues, moreover zinc is an essential element in many enzymes compositions and has an important role in reproduction, hormone secretion, growth, body immune system, in defense system and antioxidant [18].

According to scientists, two methods are developed for the synthesis of nanoparticles: top down method and bottom up method.

 

High temperature and radiation are the main factors of the physical approach (evaporation, spattering and laser deposition) for the synthesis of nanoparticles which are very harmful for the living organisms [19]. Although chemical approach (micro emulsion, spray, wet chemical and pyrolysis) is used as it is very less time consuming and produces large amount of nanoparticles, but major drawback of this approach involvement of toxic chemicals, chemicals hazards and also it is very expensive and major threat for the environment (Figure 1) [20].

On other hand biological approaches are easy to handle, cost effective, reliable, simple, ecofriendly and synthesize clean nontoxic biocompatible nanoparticles. Fundamentally, biological approach, has attracted researchers for the synthesis of nanoparticles due to less employment of toxic chemicals, being energy efficient and environmentally friendly in nature [21].

Biosynthesis of ZnO NPs is carried out by employment of unicellular and multicellular organisms such as plants, algae, fungi and bacteria and these living things manufactured ZnO NPs at large scale which are free from any harmful chemicals [22]. Nanoparticles synthesized from biological techniques exhibit the better catalytic activity and reduce the utilization of expensive and toxic chemicals. Plant extracts are the main components of green synthesis of nanoparticles, extract is isolated from various parts of plants like as fruit, flower, root, stem and leaves. Various plant extracts contained phytochemicals, for example, phenol, terpenes, saponins and protein which act as reducing and capping agents [23].

Not only plants but also microbes like as bacteria, fungi and yeast have a specific role in biological synthesis of nanoparticles (Figure 2). Nanoparticles synthesized from microbes, have multiple sizes, shapes and polydispersed to microbe cells which contain different proteins, enzymes and biomolecules which act as reduction and copping agents and enhance the stability of nanoparticles.

Synthesized nanoparticles are characterized by various techniques for the confirmation of synthesized of nanoparticles. UV-spectroscopy is used for the characterization of nanoparticles and also shows the absorption spectrum. Gupta *et al.* reported the absorption band with higher energy or lower wavelength with reducing the size of nanoparticles [24].

FT-IR techniques are employed for the identification of biomolecules in plant extract which have important role in capping, stabilization and reduction of biosynthesized nanoparticles by the shift and differences in areas of peaks.

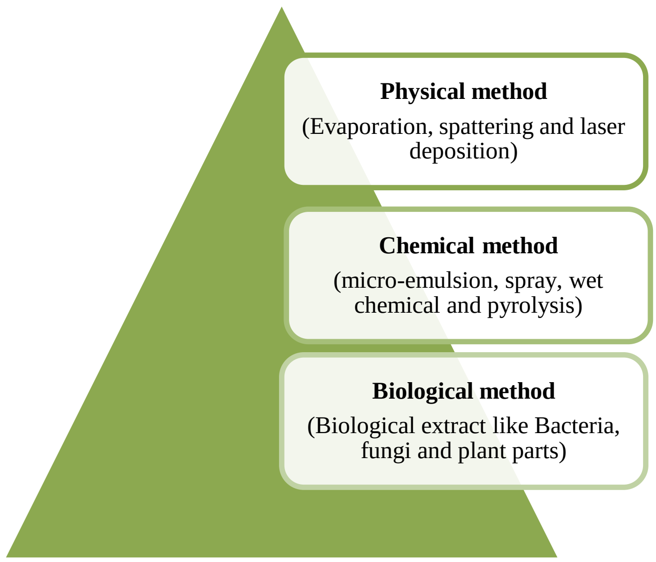


**Figure 1.** Synthesis of ZnO NPs.

SEM (Scanning electron microscope) is used for the examination of morphology of nanoparticles; EDS (Energy Dispersive Spectra) are utilized for the identification of purity of nanoparticles [25]; and XRD (X-Ray Diffraction) is used for correct confirmation, also exhibits smaller size of nanoparticles, gives narrow and strong diffraction. TEM (Transmission Electron Microscope) is employed for confirmation structure of nanoparticles.

**Biofabrication of ZnO NPs by the Employment of Plants**

Because of presence of different phytochemicals, different plant parts such as seed, fruit, root, leaf and stem have been employed for the biosynthesis of nanoparticles. Nowadays, biosynthesis is gaining more attention due to absence of toxic chemicals and presence of reducing and capping agents. Metal oxide nanoparticles synthesized from plant extract, contained secondary metabolites and enhanced the synthesis mechanism through oxidation and reduction reaction [26]. Basic concerns for the synthesis of ZnO NPs from plant parts (leaf, stem, root, flower and fruit) are that they are washed completely in running tap water then dried at room temperature accompanied by weighing and then macerating it by employing mortal pestle and mix milli-Q $H_2O$ to extract with desired concentration, and then boiled high temperature. After cooling the solution, zinc nitrate or zinc sulfate is mixed in this and then boiled at the desired temperature, a yellow color solution is obtained. Then UV-visible spectroscopy and centrifugation is used for the confirmation of synthesis of nanoparticles; for getting the crystal ZnO NPs, pellet was dried in hot air oven [27].

Various studies have reported that plants associated with family Lamiaceae, *Vitex negundo, Anisochilus cornosus* [28] and *Plectoranthus amboinicus* [29], are all employed for the amplification of nanoparticles with different sizes, and shapes such as spherical, hexagonal and rod shaped.

ZnO NPs are synthesized by the employment of leaf extract of *Calotropis gigantea* and zinc nitrate solution. Synthesized ZnO NPs have crystalline and hexagonal shape as characterized and have size range of 30–35 nm as characterized through XRD (X-Ray Diffraction) and SEM (Scanning Electron Microscope) [30].

ZnO NPs were synthesized from *Azadichta indica* leaves; confirmation and analysis was done by XRD and TEM which determine the spherical and hexagonal shape; alcohol, amide, alkane, and carboxylic acid were identified by FT-IR [31, 32].

Not only leaves extract but also flower extract have been utilized for the synthesis of ZnO NPs, for example, *Nyctanthus arbor-tristis* flower extract synthesized ZnO NPs, were characterized and identified by UV-Visible spectroscopy, XRD, DLS and TEM. ZnO NPs synthesized from flower extract showed the size range 12–32 nm and showed significant effect against the phytopathogens [33]. Flower extract of *Trifolium protense* was used for the synthesis of ZnO NPs, was confirmed through the UV-Visible spectroscopy, FT-IR, SEM with EDX. All these given techniques confirmed the synthesis of ZnO NPs size range 60–70 nm which showed the antibacterial activity against *Pseudomonas aeruginosa* ATCC 6749 [34].

Fruit extract of *Rosa canina* is utilized for the biofabrication of ZnO NPs and confirmation done by the DLS and XRD [35]. *Aloe vera* dried peel extract is used for synthesizing ZnO NPs in size range 25–65 nm and shape is spherical to hexagonal, TEM and SEM analyzed the shape, and size morphology of synthesized nanoparticles [36].

Chamomile flower (*Matricaria chamomilla*) and red tomato fruit extract (*Lycopersicon esculentum*) were used for synthesis of ZnO NPs, and analysis and characterization done by the UV-Visible spectroscopy, FT-IR, XRD, TEM, SEM with EDS and XRD determine the crystalline nature of ZnO NPs. Biosynthesized ZnO NPs from above mentioned plant extract were employed in the management of the bacterial leaf spot plant disease and also used in biomedical fields [37]. By the utilization of peel extract of orange synthesized the ZnO NPs from zinc acetate dehydrate; FT-IR determines functional groups like as carboxylic group and the biomolecule compounds present in extract enhanced the reduction and capping agents of ZnO NPs [38].

*Costus pictus D. Don* are used for fabricating ZnO NPs from leaves extract; for confirmation of synthesized nanoparticles, following techniques are employed, such as XRD determines crystalline nature, FT-IR identifies the functional group of secondary metabolites present in leaves extract like as C=O and O-H which act as capping and reducing objects and enhance the stability of nanoparticles. SEM and TEM exhibited that the green synthesized ZnO NPs have shape hexagonal and spherical, size range 11–25 nm and EDX determined zinc and oxygen [39].

Cellulosic fiber of *Gossypium spp.* synthesized the ZnO NPs; and XRD determined the size range 13 nm and spherical, rod shaped; FT-IR determined the functional group O-H and C=O present in sample which increased the stability of ZnO NPs [40].

According to another research done by researchers, not only leaves and fruit extract are utilized for synthesis of nanoparticles but also according to Krupa *et al*., Zinc oxide nanoparticles (ZnO NPs) are synthesized using coconut water from Cocos nucifera. XRD and TEM confirmed shape hexagonal to spherical and size range 20–80 nm; and FT-IR is determined biomolecules present in coconut water and also functional group O-H alcohol and carboxylic, C=O ketones group, aromatic group and aliphatic compound [41].

*Ixora coccinia* leaf extract was utilized for the fabrication of ZnO NPs; and different techniques are utilized for the confirmation of nanoparticles like SEM, XRD, FT-IR, SEM and XRD which determine the shape and size of synthesized spherical hexagonal size range 80–130 nm and FT-IR determined functional O-H hydroxyl group present in simple form [42].

Flower extract of *Vitex negundo* was utilized for the biosynthesis of ZnO NPs; analysis and characterization confirmed the synthesis of NPs; XRD and DLS determine the hexagonal shape of ZnO NPs, leaf extract synthesized NPs from this plant have size of 75–80 nm as confirmed by XRD and SEM with EDX, FT-IR determined the functional group present in the sample such as OH, C=C and C-H [43].

*Nephelium lappaceum L*. fruit peels when employed, needle shaped ZnO NPs are formed which are identified by XRD 50 nm is size, and H-O-H, O-H bending determined by FT-IR [44]. Leaf extract of *Hibiscus subdariffa* and ZnO NPs formation was identified by UV-Visible spectroscopy, FT-IR determined the functional groups involved in formation of NPs such as aromatic group C=C, C=O and alcoholic group –OH, amine group $–NH_2$, and size was confirmed by electron microscopy ranging 100 nm [45].

Fatimah *et al*. studied that if coffee powder mixed with leaves extract of *Mimosa pudica* was employed for the fabrication of ZnO NPs; characterization and analysis is done by XRD which determined that synthesized ZnO NPs have hexagonal to crystalline shape [46]. Leaf extract *Bauhinia tomentosa* was utilized for the biosynthesis of ZnO NPs, construction and identification of nanoparticles was carried out through the XRD and TEM. Biosynthesized ZnO NPs was contained crystal-hexagonal, shape and size range 49–51 nm. FT-IR determined the chemical compounds like as O-H (alcohol), C-H (alkane) and $–NH_2$ (amines) and biosynthesized ZnO NPs exhibited the antibacterial property, inhibited the growth of *Peusdomonas aeuruginosa* and *E. coli.* Leaf extract of *B. tomentosa* have different phytochemicals like as sterols, tannins, flavonoids, alkaloids, terpenoids and carbohydrates and the phytochemicals enhanced the stability and bactericidal activity of biosynthesized ZnO NPs [47].

According to Davar *et al.*, lemon juice mix with sucrose, synthesized ZnO NPs, characterized by XRD, UV-Visible spectroscopy, FT-IR, EDS and photoluminescence analysis (Table 1) [48].

 

**Table 1.** Synthesis of ZnO NPs by the plants.

| Plants | Size (nm) | Shape | Characterization | Functional Group | References |
|---|---|---|---|---|---|
| *Calotropis gigantean* | 30–35 | Crystalline and hexagonal | XRD and SEM | - | [30] |
| *Azadirchta indica* | - | Spherical and hexagonal | XRD, TEM and FT-IR | Alcohol, alkanes and carboxylic | [31, 32] |
| *Nyctanthus arbor-tristis* | 12–32 | - | UV-Visible Spectroscopy, XRD and DLS | - | [33] |
| *Trifolium protense* | 60–70 | - | UV-Visible Spectroscopy, FT-IR, and SEM with EDX | - | [34] |
| *Rosa canina* | - | - | DLS and XRD | - | [35] |
| *Aloe vera* | 25–65 | Spheriacal and hexagonal | TEM and SEM | - | [36] |
| *Matricaria chamomilla* and *Lycopersicon esculentum* | - | Crystaline | FT-IR, XRD, TEM, SEM with EDS | - | [37] |
| Orange | - | - | FT-IR | - | [38] |
| *Costus pictus* | 11–25 | Spherical and hexagonal | FT-IR, SEM with EDX and TEM | C=O and OH- | [39] |
| *Gossypium* spp | 13 | Spherical, rod shape | XRD and FT-IR | C=O and OH | [40] |
| *Cocus nuicifera* | 20-80 | Hexagonal and spherical | XRD and TEM | C=O, OH-, Ketones, aromatic carboxylic and aliphatic | [41] |
| *Ixora coccinia* | 80–13 | - | FT-IR, XRD and SEM | OH- hydroxyl | [42] |
| *Vitex negundo* | 75–80 | Hexagonal | XRD, DLS and SEM with EDX | OH-, C=C- and C-H- | [43] |
| *Nephelium* spp. | 50 | Needle shape | FT-IR | OH- | [44] |
| *Hibiscus subdariffa* | 100 | - | UV-Visible spectroscopy and FT-IR | C=C, C=O, O-H- and -$NH_2$ | [45] |
| *Mimosa pudica* | - | Hexagonal and crystalline | XRD | - | [46] |
| *Bauhinia tomentosa* | - | Hexagonal | XRD and TEM | OH-, C-H- and -$NH_2$ | [47] |
| Lemon juice | - | - | XRD, FT-IR, EDS and Photoluminescence analysis | - | [48] |

**Biosynthesis of Zinc Oxide Nanoparticles from Microorganism**

Microorganisms are gaining more interest in biological synthesis of nanoparticles. Basically, all microorganisms are not utilized for the biosynthesis of nanoparticles because microorganisms have different enzymatic reaction and metabolic mechanism. So, we need to choose the proper microorganism which is very important for the fabrication of nanoparticles. First of all, cultures are grown inspite of biofabrication of metal-metal oxide NPs that provide soluble salts which have important role in suspension of microbial cells.

Normally, Microorganisms act as biological nano-factories, showing resistance through chelation, both extracellularly and intracellularly, as well as through absorption [49].

**Biosynthesis of Zinc Oxide Nanoparticles from Bacteria**

In the biological process in the synthesis of nanoparticles, use of microbes could be either extracellular or intracellular and, in both processes, biomolecules like protein, carbohydrates and lipids are involved in cell metabolism which act as reduction and stabilizing agents which convert metal ions to metal nanoparticles (Table 2) [50]. Due to their simple manipulation and short generation time, bacteria have attracted increased attention from scientists for use in the synthesis of nanoparticles. But uses of bacteria in synthesis of nanoparticles have some disadvantages, for example, avoiding contamination, maintenance of culture medium and screening of microbes, are very time consuming processes.

*Rhodococcus pyridinivorense* and zinc sulphate are objects for the synthesis of ZnO NPs, and confirmation is done by following techniques: FE-SEM and XRD analyses determine the size range 100–130 nm, and various biochemical compounds like secondary sulphonilmide, beta lactone, hydroxyl aryl, ketone, mononuclear benzene and monosubstituted alkyne were analyzed by FT-IR [51]. Singh *et al*. reported that *Peusdomonas aeruginosa* were utilized for the synthesis of ZnO NPs, TEM, XRD and DLS analyzed the size range from 27–81 nm and spherical in shape [52]. *Aeromonas hydrophilla* synthesized ZnO NPs; AFM and XRD determined the shape spherical and oval size range 42–64 nm, functional group, monosubstituted alkylene and cis-trisubstituted function as capping agents in nanoparticles [53].

Many bacterial spp. or strains are employed in synthesis of ZnO NPs but *Bacillus lecheniformis* is one of them in which followed approaches are used such as TEM determined the size range 200 nm and functional group present in sample as O-H, N-H, -C-O- and –C-N stretching bond determined by the FT-IR [54].

Various microorganisms are utilized for the synthesis of NPs but bacteria are more beneficial in comparison to other eukaryotic microorganism due to easy handling and simple culture [55].

**Biosynthesis of ZnO NPs from Fungi**

A use of fungi in extracellular biosynthesis is very suitable due to economic potentiality and large manufacturing of nanoparticles [56]. Additionally, the fungi showed the capacity to secrete many extracellular proteins and enzymes and these bio-chemical compounds participated in reduction of metal ions into nanoparticles and enhanced the stability of nanoparticles, and produced large amount of nanoparticles [57]. Basically, *Aspergillus niger* are employed for the synthesis of nanoparticles, culture of *Aspergillus niger* was utilized for the biosynthesis ZnO NPs; confirmation done by UV-visible spectroscopy gives a peak in 320–390 nm, FT-IR identified the functional group –O-H and –C=C- are aromatic group, XRD determined crystalline size, SEM confirmed size and morphology of ZnO NPs and exhibited antibacterial activity [58]. According to Chandrasekaran *et al*., *Aspergillus terrus* was employed for the biosynthesis of ZnO NPs, SEM and XRD determined the size range 54–82 nm, spherical in shape and FT-IR identified the functional groups like as N=O, nitro compound, alkyl C=C, amide group etc. which stabilized nanoparticles (Table 3) [59].

*Aspergillus fumigates* TFR-8 was used for the synthesis of ZnO NPs and determination was done by DLS, which identified the oblate, spherical and hexagonal shape [60]. Another species of *Aspergillus strain* synthesized the ZnO NPs; SEM determined the shape spherical and size 50–120 nm [61].

**Table 2.** Biosynthesis of ZnO NPs by the Bacteria.

| Bacteria | Size (nm) | Shape | Characterization | Functional Group | References |
|---|---|---|---|---|---|
| *Rhodococcus pyridinivorense* | 100–130 | - | FE-SEM and XRD | Ketones alkyne | [51] |
| *Peusdomonas aeruginosa* | 27–81 | Spherical | TEM, XRD and DLS | - | [52] |
| *Aeromonas hydrophilla* | 42–64 | Spherical and oval | AFM and XRD | Alkylene | [53] |
| *Bacillus lecheniformis* | 200 | - | TEM | O-H, N-H, -C-O- and -C-N- | [54] |

**Table 3.** Biosynthesis of ZnO NPs by the Fungi.

| Fungi | Size (nm) | Shape | Characterization | Functional group | References |
|---|---|---|---|---|---|
| *Aspergillus niger* | 320–390 | Crystalline | FT-IR, XRD, SEM and UV-Visible Spectroscopy | –O-H and –C=C- | [58] |
| *Aspergillus terrus* | 54–82 | Spherical | FT-IR, SEM, and XRD | N=O, alkyl, C=C and amide | [59] |
| *Aspergillus fumigates TFR-8* | - | Oblate, spherical and Hexagonal | DLS | - | [60] |
| *Aspergillus strain* | 50–120 | Spherical | SEM | - | [61] |
| *Xylaria acuta* | 40–55 | Hexagonal | FT-IR, SEM with EDX, TEM and DLS | alkanes and aromatic | [62] |

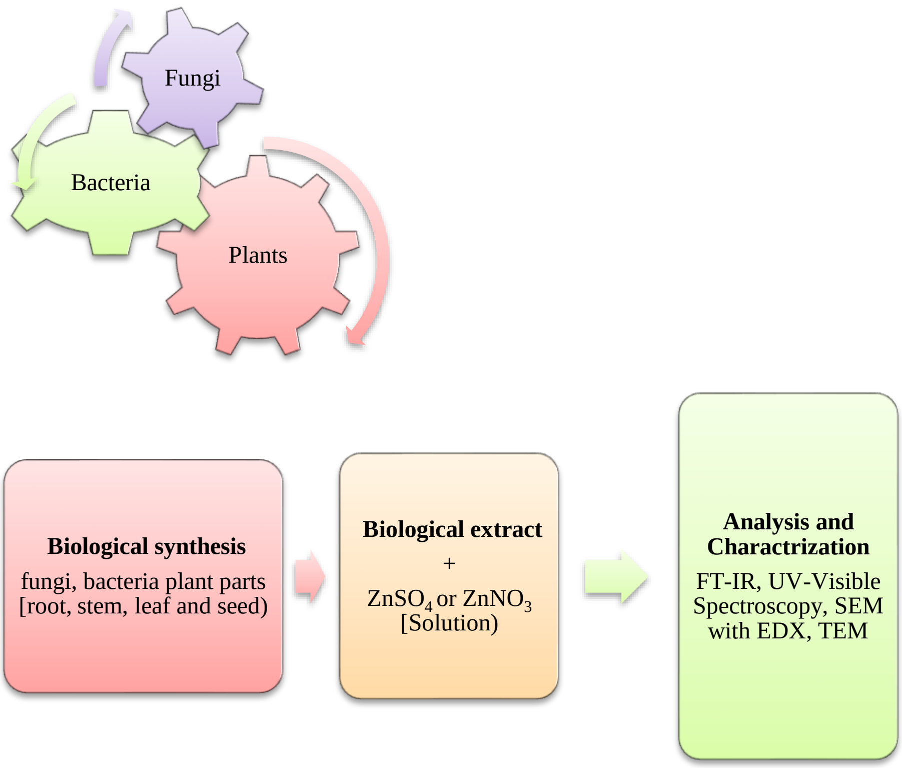


**Figure 2.** Biological synthesis of zinc nanoparticles.

*Xylaria acuta* extract is employed for the biofabrication of ZnO NPs; characterization and identification done by the following techniques: FT-IR, SEM with EDX, TEM and DLS. FT-IR determined the functional group such as alkanes aromatic groups which enhanced the stability of nanoparticles. SEM determined the shape hexagonal and size 40–55 nm [62].

## APPLICATIONS OF BIOSYNTHESIZED ZINC OXIDE NANOPARTICLES

As we all know that nanotechnology is a revolutionary technology producing lots of nanoparticles. ZnO NPs is one of them, which have wide applications. Biosynthesized ZnO NPs are used in various fields such as, nutrition in plants and animals, and humans, biomedical application act as antimicrobial agents, animal husbandry and also utilized as trace elements (Figure 3).

### Antimicrobial Activity of ZnO NPs

By the employment of new research, we can reduce the use of conventional antibiotics, ZnO NPs manufactured by the biological process act as antifungal and antibacterial agents [63, 64]. This is also reported that biosynthesized ZnO NPs reduce the growth more than the chemically synthesized.

 

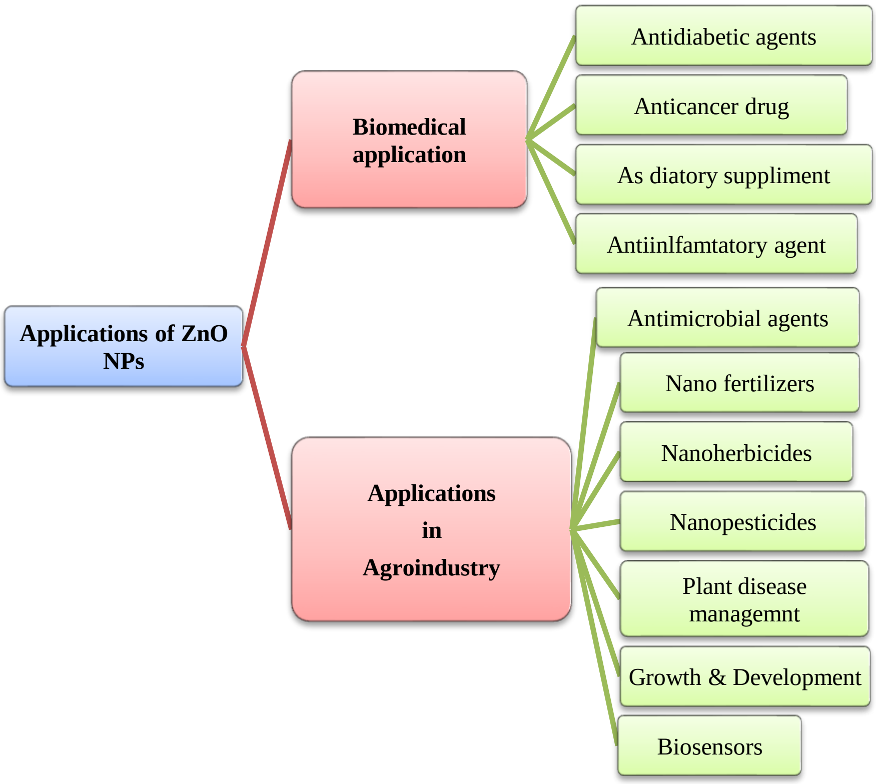


**Figure 3.** Applications of ZnO nanoparticles.

Generally, metal oxides generate reactive oxygen species (ROS) against microbial cell which leads the lysis of bacterial cell; in this regard, ZnO NPs is good microbial object against the pathogenic micro-organism.

Basically, NPs generated ROS which damage the internal macromolecules, catalytic and soluble biomolecules and plasma membrane [65]; and by this mechanism, NPs dissolved release ions which increased the toxicity, which is the main cause of microbial cell death [66, 67].

Another theory reported by Premanathan *et al.*, when ZnO NPs come in contact with bacterial cell, they affect the protein structure, membrane organization and cell permeability [68].

### As Antidiabetic Agents

It is reported that ZnO NPs have antidiabetic activity, zinc has specific role in secretion, synthesis and storage. Scientists have also reported that ZnO NPs showed more effective results as antidiabetic object in comparison to $ZnSO_4$ as it increased the zinc status, insulin level and glucose allocation [69]. According to Wahba, ZnO NPs reduced the pancreatic damage which is increased by the diabetes and also exhibited the ultrastructural and structure development, identification done by serum insulin and glucose level [70]. Researchers also reported that ZnO NPs combined with other antidiabetic agents such as valdagliptin, medicines and red sandal wood showed effective result against the diabetes [71, 72].

### Role as Anticancer

Although ZnO NPs have many biomedical implementations, but as anticancer is one of them, this is revolutionary research in medical field because cancer is a very harmful disease for human beings. ZnO NPs exhibit toxicity against the cancer cells like 3T3-L1 adipocytes and C2C12 myoblastoma cancer. ZnO NPs enhance ROS and caspases-3 (CASP3) level and reaction increases the apoptosis in C2C12 myoblastoma cancer [73]. Sasidharan reported that ZnO NPs size range from 5–200 nm protected the cells from cancer and normal cells remain unaffected [74].

**Role as Anti-inflammatory Agents**

Ilves reported that nano-zinc is more effective in comparison to bulk ZnO because ZnO NPs have capacity to perforate various layers of skin which reduces the allergic reaction [75].

**Role as Dietary Supplement in Animals**

Zinc is an essential component, so it could affect biological and physiological processes of animals like reproduction, growth, wound healing, oxygen and DNA synthesis, body immune system and protein synthesis [76]. Most important thing is that use of traditional zinc as a food supplement in animal shows the less utilization rate, so, producers and manufactures employ large quantity of dietary zinc than the normal for gaining the better result. Nowadays, by renovation of nanotechnology, production of ZnO NPs showed good impacts as food supplement in comparison to traditional zinc [77].

**Role in Agriculture industry**

Nanotechnology has special value in the changing food production, agriculture. Nanotechnology has great role in modification in agriculture. ZnO NPs have great value in agriculture and plants from last few years. Scientists have reported that ZnO NPs exhibit positive impacts and are alternative for the conventional various micronutrients, fertilizers, antimicrobial objects and fungicides.

**Role of Zn in Plants**

Micronutrients are the basic needs of plants. Zn has great role in metabolic activities and physiological process like biosynthesis of proteins, enzymes and chlorophyll [78]. Zn participates in nitrogen metabolism and amino acid biosynthesis and is essential part of ribosome which enhances the structural integrity [79, 80]. According to Hemantaranjan and Garg, Zn increased the nitrogen fixation by stimulating number of nodules in the roots of French bean [81].

**Role in Growth and Development**

ZnO NPs have capacity to enhance the growth and yield of food crops. According to Prasad *et al*., when ZnO NPs are applied at various concentrations in peanut seeds, 1000 ppm increases the seedling vigor, germination stem and root growth. ZnO NPs applied as foliar spray showed the positive impacts in flax plant by the development of photosynthetic pigment which enhanced the yield and growth of the plant [82]. Chaudhuri and Malodia reported that ZnO NPs biosynthesized from leaf extract of *Calotropis gigantia* increased the growth of Neem (*Azadraichta indica*), Milkweed (*Alstonia scholaris*) and Karanj (*Pogomia pinnata*) at seedling stage by foliar spray. *Alstonia scholaris* exhibited highest development out of these three plants [83].

ZnO NPs increased the germination rate and seed vigor at different concentrations like 100, 200 and 500 ppm in *Capsicum annum* [84]. Green synthesized ZnO NPs exhibited good source of Zn micronutrient and also promoted the growth and development in wheat plant at different concentrations of 15, 20, 125, 150 and 500 $mg.l^{-1}$ [85].

**Role in Fertilizers**

Fertilizers are those chemicals which enhanced the productivity and growth of the plants through reducing the deficiency of essential minerals and increasing the natural fertility of the plants [86]. In a simple way, nano-fertilizers alter the conventional fertilizers for soil fertility and crop productivity [87].

According to some researchers., ZnO NPs showed the positive impacts in rice when applied as foliar spray, by reducing the deficiency of Zn, by the enchantments of dehydrogenase enzymes' function, also increasing the yield parameters and growth [88, 89]; while some reported that ZnO NPs are good nanofertilizers in comparison to other harmful chemical fertilizers and act as a good plant nutrient.

**ZnO NPs in Plant Disease Management**

Due to enlarged surface area, excellence stability and small size, NPs are used in water management, increment of agriculture production and delivery system (pesticides) (Figure 4) [90].

 

### As Nano-Fungicidal Agents

Some researchers reported that ZnO NPs inhibited the growth of *Penicilium expansum* and *Aspergillus niger* [91, 92]; and some reported that ZnO NPs reduced the growth of the *Mucor plumbeu* and *Alternaria alternate*, *Rhizopus stolonifer* and *Fusarium oxysporum* [93].

Sardella *et al.* have been reported that ZnO NPs replaced the conventional fungicides in the management of the postharvest disease which is caused by the *Rhizopus stolonifer*, *Penicilium expansan*, *Botrytis cinaria* and *Aletrnaria aletrnata* [94]. ZnO NPs showed the great inhibitory effect against the *Fusarium gramininearum* and is a good agent in the enhancement of crops [95].

According to Lahuf *et al.*, when ZnO NPs are applied at seedling stage/soaking stage with biocontrol agents *Trichodrma herzianum*, it reduced the damping off disease (*Rhizoctonia solani*) in sunflower [96].

When plant pathogenic fungi come in contact of host plant, pathogens secret some chemicals i.e. called mycotoxins; biosynthesized ZnO NPs neutralize these chemicals and enhance the plant growth [97].

### ZnO NPs As bacterial plant pathogens

Nanoparticles showed the better result against the plant pathogenic bacteria by degeneration of cell membrane; lysis the bacterial cell, and then cytoplasmic content is released out [98].

ZnO NPs showed great inhibitory effect against plant pathogenic bacteria like citrus canker (*Xanthomonas citri*) [99], (*Xanthomonas auxonopodis pv. phaseoli*) [100], a pathogen of lentil.

Ogunyemi *et al*. reported that ZnO NPs biosynthesized from the extract of *Olea europea* showed the great inhibitory effect against the *Xanthomonas oryzae pv. oryzae* [101].

### ZnO NPs Against the Plant Parasitic Nematodes

ZnO NPs exhibited the toxicity against the plant pathogens and other microorganism according to Hrács *et al*. [102]. ZnO NPs showed the negative impacts against the *Xiphinema vulttezi* which is a plant parasitic nematode.

Biosynthesized ZnO NPs from the algae *Ulva furciata* inhibited the growth of the root knot nematodes in banana. ZnO NPs inhibited the J2 stage of *Meloidogyne incognita* by creating the disorganization and noxious effect in the cell [103].

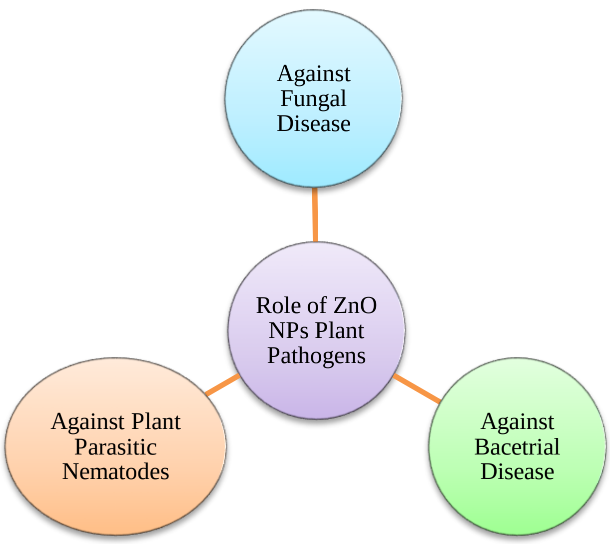


**Figure 4.** ZnO NPs in plant disease management.

 

**ZnO NPs as Herbicides**

When NPs or nano-formulations are applied as herbicides, it can reduce the harmful effect of chemical herbicides on the environment and prevent other species from the negative impacts like microorganisms, insects and plants [104]. NPs are very good objects as herbicides in the inhibition of growth of unwanted plants; nanoherbicides do not have any negative impact on the environments [105].

After the development of nanotechnology ZnO NPs can be good herbicides in comparison to other conventional and chemical herbicides and it have capacity to reduced 80–90% glyphosate herbicides [106].

**ZnO NPs as Pesticides**

There are many agriculture- or biopesticides available in the market but still Zn either single or combined with Cu is widely used as pesticides. According to US-EPA, zinc salt in three forms: zinc phosphate, zinc oxide and zinc chloride, are greatly employed as pesticides. Zinc oxide is a good pesticide as other previous agents [107].

**ZnO NPs as Biosensors**

ZnO NPs have very good qualities for making electrothermal sensors and biosensors due to high adsorption quality, strong surface area and high catalytic ability. So, ZnO NPs are employed as biosensors in environmental pollution monitoring, pharmaceutical, food safety and medical diagnosis [108]. In biosensing, ZnO NPs combined with QD (nanocrystal) and kasugamycin (KAS), special type of antibiotic which is employed in the management of bacterial fruit blotch [109].

The better plant sensing system reduces the use of expensive chemical-based fertilizers, pesticides and herbicides and protect the plant from stress created by the climate. By the biosensors method, ZnO NPs combined with $CeO_2$ (cerium oxide nanoparticles) through the scavenging reactive oxygen protected the plant from the salinity and heat stress.

**CONCLUSION**

The present review brings out the biosynthesis and importance of ZnO NPs in medicals and agriculture. We have seen that the ZnO NPs can be synthesized by physical, chemical and biological techniques. But biological method is very eco-friendly for the environment, easy, and safe in comparison to physical and chemical methods, as it does not contain any chemicals hazards and toxic substances.

Biosynthesized ZnO NPs have wide implementation in different fields like medical, biotechnology, cosmetics and agriculture. ZnO NPs have many uses, but in medical field, it acts as a revolutionary object in anticancer and antidiabetic drug which is a very crucial disease nowadays. There are many studies which proved that biosynthesized ZnO NPs exhibited the positive impact in the management of plant diseases and inhibited growth of plant pathogen (fungi, bacteria and plant parasitic nematodes) and enhanced plant growth. ZnO NPs could be good antimicrobial agents which act as nanofungicides, bactericides and show antinematicidal properties and protect the plant from harmful plant pathogens. Recent development of biosensors is very advanced research of nanotechnology in agriculture as it can easily detect plant health and plant pathogens.

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