

# Biogenic Synthesis of Nanoparticles and Potential Applications: An Eco-Friendly Approach

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## Abstract

The uprising in materials science has been hosted by previous few decades. There has been a substantial research interest in the area of using particulate systems to accomplish various approaches. The conception or synthesis of material with nanometer-scale precision (nanoparticles), by means of material science, is nanotechnology. Nanoparticles are defined as particulate dispersal or solid particles, with a size in the range of 1-100 nm.

This review intends to present biosynthesis and application of nanoparticles *in minutiae*. Here, we discussed different synthesis methods, *i.e.* chemical, physical and biogenic synthesis of nanoparticles. The potential come together between nanotechnology and biological science is enormous. Realistic biologics depends on units that have nanoscale dimensions (proteins, viruses, molecular motors, extra cellular matrix). Our major dictum is to focus the various facet of synthesis of nanoparticles, characterization, and its imperative application by giving accent on biogenic synthesis of nanoparticles.

**Keywords:** Nanoparticles; Biosynthesis; Potential application

## Introduction

Nanotechnology is facilitating technology that deals with nanometer sized items [1]. The exercise of nanomaterials in biotechnology unites the fields of biology and material science. Nanoparticles put forward an essentially useful platform, demonstrating unique properties with potentially wide-ranging application [2]. Owing to the many rewards over non-biological systems, several research groups have oppressed the use of biological systems for the synthesis of nanoparticles. The exclusive properties and usefulness of nanoparticles arise from a variety of aspects, including the similar size of nanoparticles and biomolecules, such as proteins and polynucleic acids [3]. The nanoparticles synthesized by means of biogenic approach present good polydispersity, dimensions and stability. The nanoparticles are synthesised through physical, chemical and biological methods [4]. The physical and chemical methods are extremely pricey [5]. The biological methods of nanoparticles synthesis would assist to remove ruthless processing conditions, by allowing the synthesis at physiological pH, temperature, pressure, and at the same time, at negligible cost. Huge number of micro organisms have been found competent of synthesizing inorganic nanoparticles composite, either intra or extracellularly. Due to implausible properties, nanoparticles have turned into noteworthy in many fields in the recent years, such as energy, health care, environment, agriculture, etc. The preparation of nanoparticles is established either by (i) Nanoparticles synthesis, or by (ii) Processing of nanomaterials into nanostructure particles [6].

In this review, we have discussed general approaches to the synthesis of nanoparticles by various methods and applications. The research and product developments in the vicinity of nanotechnology have progressively increased, chiefly due to new and valuable properties of nanomaterials. New nanomaterials, an inherent part of nanotechnological developments, allow on the one hand, new products and solutions [7]. The probable applications of nanotechnology and nanoparticles in different fields have reformed the sciences and industries that are discussed here.

## Synthesis of Nanoparticles

### Chemical synthesis

Chemical method of synthesis is valuable as it takes tiny period of

time for synthesis of large quantity of nanoparticles. Nevertheless, in this method, capping agents are necessary for size stabilization of the nanoparticles. Nanoparticles have been synthesized, most recurrently by three chemical techniques:

- Dispersion of preformed polymers
- Polymerization of monomers
- Ionic gelation or coacervation of hydrophilic polymers

**Dispersion of preformed polymers:** A number of methods have been recommended to prepare nanoparticles from PLA (polylactic acid), PLG (poly-D-L-glycolide), PLGA (poly-D-L-lactide-co-glycolide) and PCA (Poly- $\epsilon$ -caprolactone), by dispersing the preformed polymers [8,9].

**Polymerization of monomers:** Nanoparticles can moreover be prepared by polymerization of monomers. Polymeric nanoparticles achieved from copolymers of methacrylic acid, acrylic esters or metacrylics, have been extensively been used [10].

**Ionic gelation or coacervation of hydrophilic polymers:** During this method, ionic gelation of the material experienced transition from liquid to gel due to ionic interactions. Chitosan, gelatine and sodium alginate is utilized for preparation of hydrophilic nanoparticles by ionic gelation [11]. Nanoparticles can be prepared from a wide range of materials such as proteins, polysaccharides and synthetic polymers, etc. (Figure 1); usually used reductants are borohydride, citrate, ascorbate and elemental hydrogen [12,13]. Furthermore, chemicals reagents used

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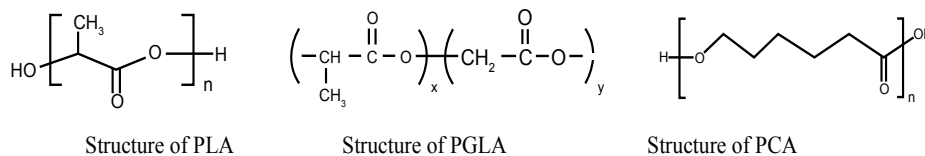


Figure 1: Structure of different polymers used for nanoparticle synthesis.

normally for nanoparticles synthesis and stabilization are toxic and lead to byproducts that are not ecofriendly [14].

### Physical synthesis

The above method is hardly ever used methods in physical processes; metal nanoparticles are synthesized by evaporation–condensation, which might be carried out using a tube furnace at atmospheric pressure. The starting material inside a boat centered at the furnace is vaporized into a carrier gas. Nanoparticles of different materials such as Ag, Au, PbS and fullerene have formerly been produced using the evaporation/condensation techniques [15-18]. Initially, the design and description of two-dimensional arrays of colloidal Au particles are existing, and later Grabar reported a new loom to develop Au colloid through surface-enhanced Raman scattering (SERS) substrates. Au colloid monolayers possess a set of features that make them very attractive for both basic and applied uses, including uniform roughness, high stability, and biocompatibility [19]. Recently Mirza and Shamshad [20] investigated the gold nanoparticles (Au NPs) functionalized with an anticancer drug, doxorubicin. Their study laid the basis of a linking methodology *via* hybrid multi drug, and receptor labelled NPs might be developed, which may provide an alternative design for nanosized drug-delivery system.

### Biological synthesis

Our key purpose is to highlight on the biological synthesis of nanoparticles, because of its easiness of rapid synthesis, controlled toxicity, controlling on size characteristics, reasonable, and eco friendly approach. A sum of natural sources is there for nanoparticle synthesis, together with plants, fungi, yeast, bacteria, etc. Additionally, the unicellular and multicultural organisms are able to synthesise intracellular and extra cellular inorganic nanoparticles. The various sources of nanoparticles synthesis are enlisted in table 1.

**Nanoparticle synthesis by plant extracts:** Make use of plants in the synthesis of nanoparticles has drawn more interest of workers because it provides single step biosynthesis process. Plants tender a superior option for synthesis of nanoparticle, as the protocols involving plant sources are free from toxicants; furthermore, natural capping agents are readily supplied by the plants (Figure 2).

The production of gold and silver nanoparticles using *Geranium* extract [21], *Aloe vera* plant extracts [22], sundried *Cinnamomum camphora* and *Azadiracta indica* leaf extract has been explained [23-25]

Inexpensive reduction of silver and gold ions present concurrently in solution, during exposure to plant leaf extract, generates bimetallic silver and gold shell nanoparticles. The information is also available for the synthesis of silver nanoparticles, using *Plumeria rubra* plant latex [25]. Nanoparticle synthesis furthermore carried out using *Szyygium aromaticum* bud extract, *Murraya koenigii* leaf extract. This synthesis is owing to the natural reducing agent eugenol and could be carbazoles

present in the extracts correspondingly [26,27]. Biosynthesis of gold nanoparticles utilizing the leaf extract of *Mirabilis jalapa* was explicated [28].

**Nanoparticle synthesis by bacteria:** In previous years, synthesis of nanoparticles using bacteria has enlarged comprehensively due to its immense application. *Bacillus species* has depicted to synthesise metal nanoparticles, researchers showed the ability of bacteria to decrease silver and fabrication of extracellularly, consistently circulated nanoparticles, ranging from 10-20 nm size [58]. The Silver producing bacteria isolated from the silver mines exhibit the silver nanoparticles accumulated in the periplasmic space of *Pseudomonas stutzeri* AG259 [59]. Bacteria are also used to synthesise gold nanoparticles. Sharma et al. [60] reported that whole cells of a novel strain of *Marinobacter pelagius* are applicable for stable, monodisperse gold nanoparticle formation. Prasad et al. [61] has been reported use of *Lactobacillus* strains to synthesise the titanium nanoparticles. The understanding of natural processes will apparently help in the discovery of entirely new and unexplored methodology of metal nanoparticle synthesis.

**Nanoparticle synthesis by fungi:** Biological production of nanoparticles by fungi is determined nowadays because of their reception towards toxicity, higher bioaccumulation, comparatively economic, effortless synthesis method and simple downstream processing and biomass handling.

Extracellular biosynthesis of silver nanoparticles by *Aspergillus niger* [41], *Fusarium solani* [44] and *Aspergillus oryzae* are reported to produce silver nanocrystals [42]. The *Pleurotus sajor caju* was also used for synthesis of nanoparticles extracellularly [45]. The spherical nanoparticle can be synthesized by *Trichoderma viride* [46]. Prologue of silver ions to *Fusarium oxysporum* leads to synthesis of stable Ag hydrosols [62]. *Phoma glomerata* has been traced to produce silver nanoparticles, and its efficiency against *E.coli*, *S. aureus* and *P. aeruginosa* has been assessed [63]. The genus *Penicillium* seems to have a superior contender for the silver nanoparticle synthesis, where production proceeds *via* extracellular mechanism [64].

**Nanoparticle synthesis by yeast:** The extracellular synthesis of nanoparticles in huge quantities, with straightforward downstream processing, has been reported by Kowshik et al. [48]. This group has been involved in isolation of silver tolerant yeast strain MKY3, by inoculating with aqueous silver nitrate. The formation of 2-5 nm silver nanoparticles takes place in the forced ecological conditions. The synthesis of cadmium nanoparticles by using *Candida glabrata* and *Schizosaccharomyce pombe* has been reported by Dameron et al. [49]. The silver and gold nanoparticles biosynthesis was also investigated by Mourato et al. [50], using an extremophilic yeast strain isolated from acid mine drainage. The marine yeast *Rhodospiridium diobovatum* has been explored for intracellular synthesis of stable lead sulfide nanoparticles [51].

**Nanoparticle synthesis by biological particles:** Biological particles

Source	Types and size of NPs (nm)	References
<b>Plant</b>		
<i>Azadirachta indica</i>	Ag,Au 50/100	Shankar et al. [21]
<i>Aloe vera</i>	Au 50/350	Chandran et al. [22]
<i>Cinnamomum camphora</i>	Ag 50	Huang et al. [23]
<i>Syzygium aromaticum</i>	Ag,Au ---	Kalpna devi et al. [29]
<i>Murraya koenigii</i>	Ag	Christensen et al. [27]
<i>Plumeria rubra</i>	Ag	Patil et al. [25]
<i>Citrus aurantium</i>	Ag	Pala et al. [30]
Geranium leaf plant extract	Ag 16/40	Shankar et al. [21]
<i>Jatropha curcas</i>	Ag >20	Pala et al. [30]
<i>Tridax procumbens</i>	Ag >20	Pala et al. [30]
<i>Hibiscus rosa sinensis</i>	Ag 13/20	Daizy [31]
<b>Bacteria</b>		
<i>Bacillus cereus</i>	Ag 5	Ganesh Babu and Gunasekaran [32]
<i>Bacillus thuringiensis</i>	Ag 10/20	Jain et al. [33]
<i>Escherichia coli</i>	Ag 30/50	Gurunathan et al. [34]
<i>Escherichia coli</i>	Cds---	Sweeney et al. [35]
<i>Lactobacillus</i> strains	Ag,Au 15/40	Sintubin et al. [36]
<i>Pseudomonas stutzeri</i>	Ag>200	Klaus et al. [37]
<i>Corynebacterium</i>	Ag 5/15	Zhang et al. [38]
<i>Staphylococcus aureus</i>	Ag 150/180	Nanda and Saravanan [39]
<i>Ureibacillus thermosphaericus</i>	Ag 1/100	Juibari et al. [40]
<b>Fungi</b>		
<i>Aspergillus niger</i>	Ag 20	Gade et al. [41]
<i>Aspergillus oryzae</i>	Ag 5-50	Binupriya et al. [42]
<i>Fusarium oxysporum</i>	Ag 1/5	Duran et al. [43]
<i>Fusarium solani</i>	Ag 5/35	Ingle et al. [44]
<i>Pleurotus sajor-caju</i>	Ag 5/50	Nithya and Raganathan [45]
<i>Trichoderma viride</i>	Ag 10/40	Thakkar et al. [46]
<i>Klebsiella pneumoniae</i>	Se 100/400	Fesharaki et al. [47]
<b>Yeast</b>		
Silver-tolerant strain MKY3	Ag 2/20	Kowshik et al. [48]
<i>Candida glabrata</i>	CdS 50/150	Dameron et al. [49]
<i>Schizosaccharomyce pombe</i>	CdS 50/150	Dameron et al. [49]
Extremophilic yeast	Ag	Mourato et al. [50]
<i>Rhodospiridium dibovatum</i>	PbS	Seshadri et al. [51]
<b>Biomolecules</b>		
DNA	Au/CdS	Mahtab et al. and Shaiu et al. [52] [53]
Proteins	Au	Safer et al. and Hainfeld and Furuya [54] [55]
Immunoglobulins, serum albumins	Au	Shenton et al. and Beesley [56] [57]

Table 1: Altered sources of nanoparticles synthesis.

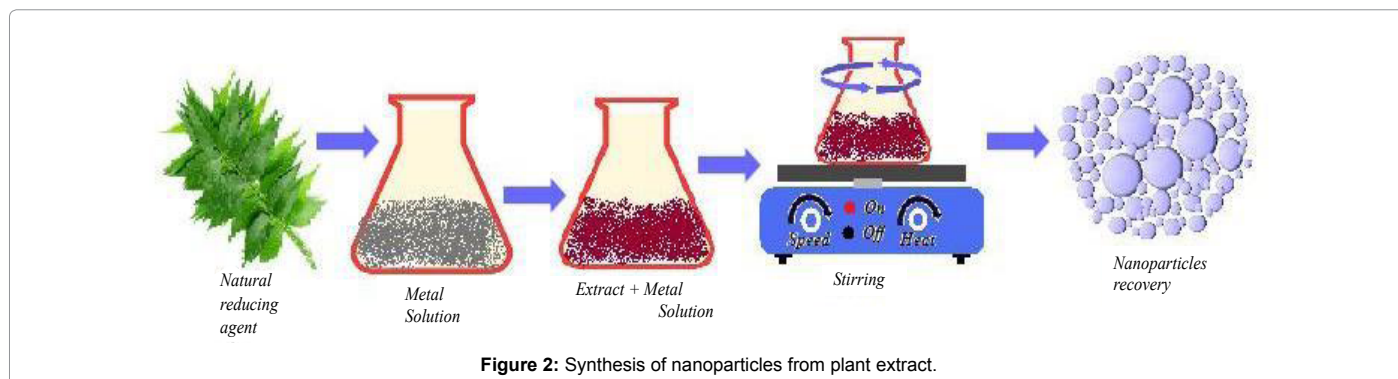
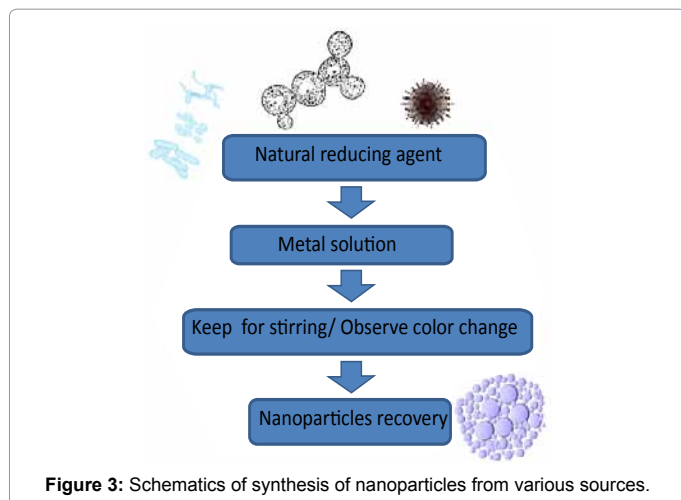


Figure 2: Synthesis of nanoparticles from plant extract.

like viruses, proteins, peptides and enzymes could be exploited for biosynthesis of nanoparticles (Figure 3). For the mineralization of inorganic materials, Cowpea chlorotic mottle virus and cowpea mosaic virus have been employed [65,66]. Tobacco mosaic virus helps for the

mineralization of sulphide and crystalline nanowires [67]. Peptides are competent of nucleating nanocrystal growth, and have been recognized from combinatorial screens and demonstrated on the surface of M13 bacteriophage [68].



## Characterization

Characterization of nanoparticles is significant to appreciate and control nanoparticles synthesis and applications. Nanoparticles characterization is executed using a range of diverse techniques like scanning and transmission electron microscopy (SEM, TEM), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), dynamic light scattering (DLS), powder X-ray diffractometry (XRD), and UV-Vis spectroscopy. These techniques are helpful to resolve diverse parameters such as particle size, shape, crystallinity, fractal dimensions, pore size and surface area. Additionally, orientation, intercalation and dispersion of nanoparticles and nanotubes in nanocomposite materials could be decided by these techniques. The morphology and particle size possibly will be determined by TEM, SEM and AFM. The improvement of AFM over conventional microscopes such as SEM and TEM is that AFM technique measures 3D images, so that particle height and volume can be intended. Moreover, dynamic light scattering is applied for determination of particles size distribution. Furthermore, X-ray diffraction is exercise for the determination of crystallinity, while UV-Vis spectroscopy is utilized to confirm sample formation by exhibiting the Plasmon resonance [69-78].

## Applications

There are widespread applications of nanoparticles such as pharmaceuticals, cosmetics, food and beverages, agriculture, surface coating, polymers, etc. (Figure 4); few of them are discussed here.

### Nanoparticles as potent antimicrobial agent

The silver nanoparticles synthesised using an endophytic fungus, *Pestalotia sp.*, isolated from leaves of *Syzygium cumini* has antibacterial activity against human pathogens, i.e. *S. aureus* and *S. typhi* [79]. Silver nanoparticles showed powerful bactericidal potential against both Gram-positive and Gram-negative bacteria. Numbers of silver nanoparticles are used against pathogenic bacteria. The bactericidal prospective of silver nanoparticles against the MDR bacteria are also investigated [80,81].

### Nanoparticles in electrochemical sensors and biosensors

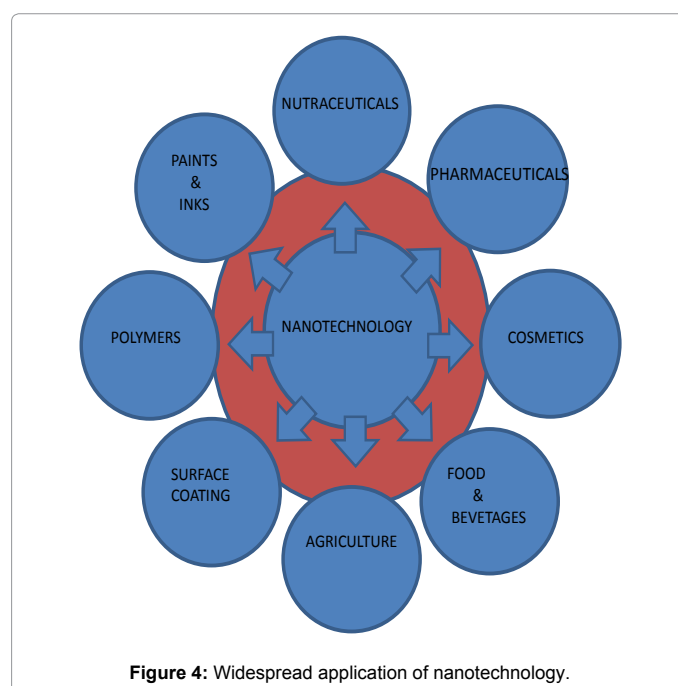
A set of forms of nanoparticles such as oxide, metal and semiconductor nanoparticles have been utilized for constructing electrochemical sensors and biosensors, and these nanoparticles

play diverse roles in different sensing systems. The significant functions provided by nanoparticles comprise the immobilization of biomolecules, the catalysis of electrochemical reactions, the improvement of electron transfer among electrode surfaces and proteins, labelling of biomolecules, and still acting as reactant. The exclusive chemical and physical properties of nanoparticles make them enormously appropriate for designing new and enhanced sensing devices, particularly electrochemical sensors and biosensors. The gold nanoparticles are most frequently used for the immobilization of proteins [82]. Xiao et al. [83] initially attached gold nanoparticles to gold electrodes modified with cysteamine monolayer, and then effectively immobilized horseradish peroxidase on these nanoparticles. An additional type of biomolecules, DNA, can also be immobilized with nanoparticles, and used for the creation of electrochemical DNA sensors. In command to immobilize DNA onto the surfaces of nanoparticles, the DNA strands are frequently modified with meticulous functional groups that can work together powerfully with convinced nanoparticles [84].

### Nanoparticles in medicine and healthcare

Nanoparticles have been utilised newly to develop the present imaging techniques for *in vivo* diagnosis of biomedical disorders. Presently, Iron oxide nanoparticles are being used in patients for both diagnosis and therapy, leading to more effective medication with less unfavourable effects [85]. An exclusive, susceptible and greatly explicit immunoassay system based on the aggregation of gold nanoparticles that are coated with protein antigens, in the attendance of their corresponding antibodies, was also developed [86].

Nanoparticles, as drug delivery systems, are capable to uplift the several crucial properties of free drugs, such as solubility, *in vivo* stability, pharmacokinetics, biodistribution and enhancing their efficiency [87]. In this facet, nanoparticles could be used as potential drug delivery systems, owing to their advantageous characteristics. As an illustration of cellular delivery, mixed monolayer protected gold clusters were oppressed for *in vitro* delivery of a hydrophobic



fluorophore [88]. Pandey and Khuller [89] designed nanoparticle for the growth of oral drug delivery system, and recommended that nano-encapsulation may be useful for developing an appropriate oral dosage form for streptomycin, and for other antibiotics that are, if not injectable [89]. Elechiguerra et al. [90] demonstrated the interaction of metal nanoparticles with viruses and explained that silver nanoparticles experience a size-dependent interaction with HIV-1; the nanoparticles of 1-10 nm close to the virus. The usual spatial understanding of the attached nanoparticles, the centre-to-centre space among nanoparticles and the bare sulfur-bearing residues of the glycoprotein knobs suggested that, through favoured binding, the silver nanoparticles prohibited the HIV-1 virus from binding to host cells. Currently, the majority imaging studies using gold nanoparticles are carried out in cell culture [90]. The functional cellular imaging about single molecules has been reported by Peleg et al. [91], captivating benefit of the enhanced second harmonic signal by antibody conjugated gold nanospheres.

The exploitation of nanoparticles in cosmetics and medicine coating is widely increased day by day. The metal oxides in nanoparticle such as zinc oxide and titanium dioxide now emerge on the component records of household products, as general and assorted as cosmetics, sunscreens, toothpaste, and medicine [92].

### Nanoparticles in agriculture

**Nanotech delivery systems for pests, nutrients and plant hormones:** In the proficient use of agricultural natural assets like water, nutrients and chemicals during precision farming, nanosensors and nano-based smart delivery systems are user friendly. It makes the use of nanomaterials and global positioning systems with satellite imaging of fields, farm supervisors might distantly detect crop pests or facts of stress such as drought. Nanosensors disseminated in the field are able to sense the existence of plant viruses and the level of soil nutrients. To put aside fertilizer consumption and to minimize environmental pollution, nanoencapsulated slow release fertilizers have also become a style [93].

To check the quality of agricultural manufacture, nanobarcode and nanoprocessing could be used. Li et al. [94] used the idea of grocery barcodes for economical, proficient, rapid and effortless decoding and recognition of diseases. They created microscopic probes or nanobarcode that may perhaps tag multiple pathogens in a farm, which may simply be detected using any fluorescent-based tools [94].

All the way through nanotechnology, scientists are capable to study plant's regulation of hormones such as auxin, which is accountable for root growth and seedling organization. Nanosensors have been developed that reacts with auxin. This is a step forward in auxin research, as it helps scientists know how plant roots acclimatize to their environment, particularly to marginal soils [95].

**Nanotechnology for crop biotechnology:** Nanocapsules can facilitate successful incursion of herbicides through cuticles and tissues, allowing slow and regular discharge of the active substances. This can be act as 'magic bullets', containing herbicides, chemicals or genes which target exacting plant parts to liberate their substance [96].

Torney et al. [97] has exploited a 3 nm mesoporous silica nanoparticle in delivering DNA and chemicals into isolated plant cells. Mesoporous silica nanoparticle are chemically coated and act as containers for the genes delivered into the plants, and triggers the plant to take the particles through the cell walls, where the genes are put in and activated in a clear-cut and controlled way, without any toxic

side effects. This technique firstly has been applied to establish DNA fruitfully to tobacco and corn plants [97].

### Conclusions

Nanoparticles present an extremely gorgeous platform for a diverse range of biological applications. As it provides the single step process for biosynthesis of nanoparticles attracts more researchers to go for future developments in the area of electrochemical sensor, biosensors, medicine, healthcare and agriculture.

In this review, we express nanoparticles synthesis using biological methods. These methods are environment friendly and commercially economic. Relationship of special synthesis methods, namely physical, chemical and Biological methods generous highlighting to biogenic synthesis is documented here. Further progresses are desirable in order to revolve the impression of nanoparticle technology into a rational practical approach.

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