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Green Nanoparticles: Synthesis and Applications

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Abstract: *The increased use of nanoparticles in biomedical sciences, electronics, and drug delivery has led to development of various methods of synthesizing nanoparticles using physical, chemical and biological methods. But the limitation like toxicity, hazardous chemicals and high cost of production led to develop alternative methods for production of nanoparticles. Green synthesis of nanoparticles is an alternative and emerging area of research. The green synthesis of nanoparticles using microorganisms is a promising approach which is eco friendly and cost effective method.*

Keywords: *nanoparticles, Green synthesis, Nanotechnology, Microorganisms*

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I. Introduction

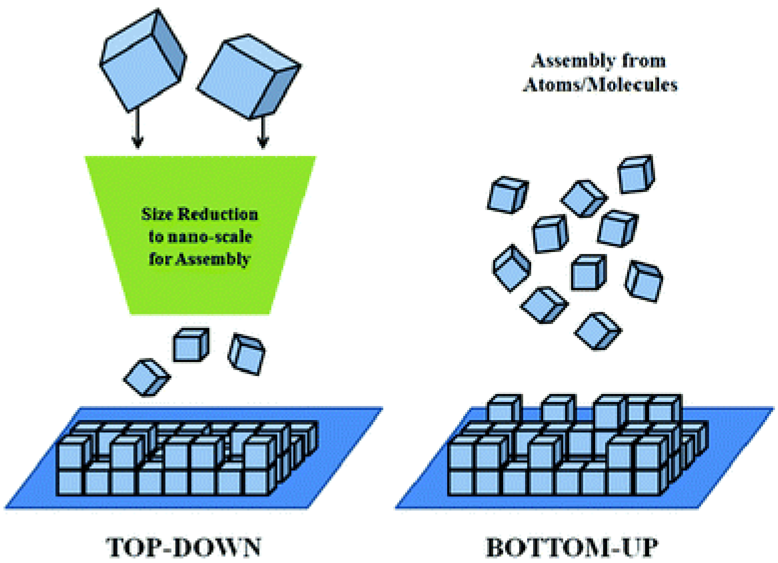
The term Nanotechnology defines the process of designing, synthesis and application of materials of size in the range of nanoscale. Any particle having size 1 nm to 100 nm is considered to be a nano-particle and the materials or chemicals in this range are commonly referred to as namomaterials. The common examples of nanomaterials are nanofibres, nanorods, nanosheets, nanospheres etc. Now-a-days nanomaterials find great applications in healthcare, electronics, cosmetics and other areas of research.

II. Nanoparticles Synthesis Approach

There are two general approaches to the synthesis of nanomaterials and the fabrication of nanostructures: Bottom up and top down approach.

Bottom-up approach include the miniaturization of materials components (up to atomic level) with further self assembly process leading to the formation nanostructures. During self-assembly the physical forces operating at nanoscale are used to combine basic units into larger stable structures. Typical examples are quantum dot formation during epitaxial growth and formation of nanoparticles from colloidal dispersion.

Top-down approach use larger (macroscopic) initial structures, which can be externally-controlled in the processing of nanostructures. Typical examples are etching through the mask, ball milling, and application of severe plastic deformation (Agarwal, et al. 2017).



Source: (Birol et al., 2013)

Fig.1: Top-down and bottom-up approach to Nanoparticle Synthesis

Methods of Nanoparticles Synthesis

Nanoparticle synthesis can be done by different methods like physical, chemical and green methods (Afifi, et al.2015; Chen, et al. 2015; Vitosh, et al. 1994). The physical methods include: laser ablation (Mafune et al. 2001), lithography (Zhang and Wang. 2008) and high-energy irradiation (Treguer, et al. 1998). The physical method involves the use of costly equipment, high temperature and pressure, large space area for setting up of machines (Chandrasekaran, et al. 2016).

In the chemical approach, chemical reduction, electrochemistry, and photochemical reduction (Chen, et al. 2001; Eustis et al. 2005; Rodriguez et al. 2002; Starowiicz et al. 2006; Frattini et al. 2005) are the most common methods for synthesis of nanoparticles. The chemical method involves the use of toxic chemicals which can be hazardous to the person and the environment (Agarwal, et al. 2017). Moreover the toxicity of the chemicals used in physical and chemical methods make it unsafe for use in medical field. As compared to conventional methods, biological methods are considered safe and ecologically sound for the nanomaterial fabrication. Therefore an environment and eco friendly approach for synthesis of nanoparticles using microorganisms and different plants commonly referred to as **Green Approach** is the most researched area for synthesis of nanoparticles holds immense potential.

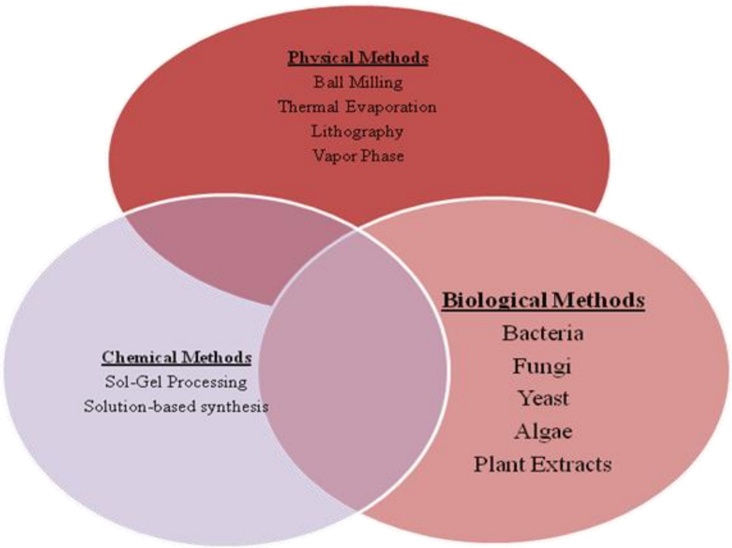


Fig. 2: Methods of Nanoparticle Synthesis

Biological synthesis of gold, silver, platinum, palladium, selenium, zinc, copper particles by bacteria, actinomycetes, fungi and yeasts have been reported worldwide (Shah et al. 2015).

The green biosynthesis of nanoparticles can be achieved by selecting an environmentally acceptable solvent with eco-friendly reducing and stabilizing agents (Jegadeeswaran, et al. 2012). These biological systems can transform inorganic metal ions into metal nanoparticles via the reductive capacities of the proteins and metabolites present in these organisms (Makarov, et al. 2014).

Source: (TERI Webpage)

Figure 3: Green Technology

Nanoparticle synthesis using Microorganisms

Due to their eco-friendliness and cost effectiveness, microorganisms as nanofactories have received much attention in recent years. Various microorganisms: bacteria, yeasts, fungi, algae have been extensively studied for synthesis of nanoparticles-both extracellular and intracellular. The extracellular biosynthesis of nanoparticles has been extensively studied because it eliminates the downstream processing steps required for the recovery of nanoparticles in intracellular methodologies, including sonication to break down the cell wall, several centrifugation and washing steps required for nanoparticle purification (Singh, et al. 2016). A number of other factors like metal-resistant genes, proteins, peptides, enzymes, reducing cofactors, and organic materials also play important role as reducing agents.

Singh et al. 2016 have explained the synthesis of nanoparticles both extracellularly and intracellularly using microorganisms.

In extracellular synthesis, biomass is harvested by centrifugation after culturing the microorganisms in a rotating shaker under optimum growth conditions. The supernatant recovered after centrifugation is incubated with metal salt solution to synthesize the desired nanoparticles of the metal ion. A color change in the reaction mixture is the first qualitative indication that nanoparticles are being synthesized. For ex.: for silver nanoparticles, the color changes to deep brown and for gold nanoparticles, it changes from ruby red to a deep purple color. Tyndall effect, a property of colloidal particles in solution, is used to detect the presence of nanoparticles in solution **(**Poinern, 2014**).** After the reaction, nanoparticles are separated from the colloid by high speed centrifugation, washed thoroughly in water/solvent (ethanol/methanol) and collected in the form of a bottom pellet.

In the intracellular synthesis of nanoparticles, biomass is harvested after culturing microorganisms under optimum growth conditions. The biomass is washed thoroughly with sterile water and incubated with metal ion solution. A color change is an indication of the nanoparticles synthesis. After the incubation period, biomass is subjected to ultrasonication, washing and centrifugation which release the nanoparticles after breakdown of cell wall. Finally, the released nanoparticles are washed, centrifuged and collected.

The nanoparticles can also be synthesized using various plant extracts. For this, plant parts like root, leaf, bark are washed, cut into small pieces under sterile conditions and boiled to obtain the extract. The extract is further purified by filtration and centrifugation. The purified plant extract, metal salt and water are incubated to obtain the nanoparticles of the desired metal ion.

The commonly used bacterial species for the synthesis of nanoparticles include Actinobacter sp., Escherichia coli, Klebsiella pneumonia, Lactobacillus spp., Bacillus cereus, Corynebacterium sp., and Pseudomonas sp. (Mohanpuria, et al.2008; Iravani, et al.2014; Sunkar, et al.2012, Tollamadugu, et al. 2011; Shah, (et al.2015).

The enzyme mainly responsible for conversion of metal ions into metallic nanoparticles is resductase enzyme like nitrate reductase enzyme for silver nanoparticle synthesis in B. licheniformis (Singh. et al, 2016). The general mechanism of naoparticle synthesis using microorganism is depicted in Figure: 4.

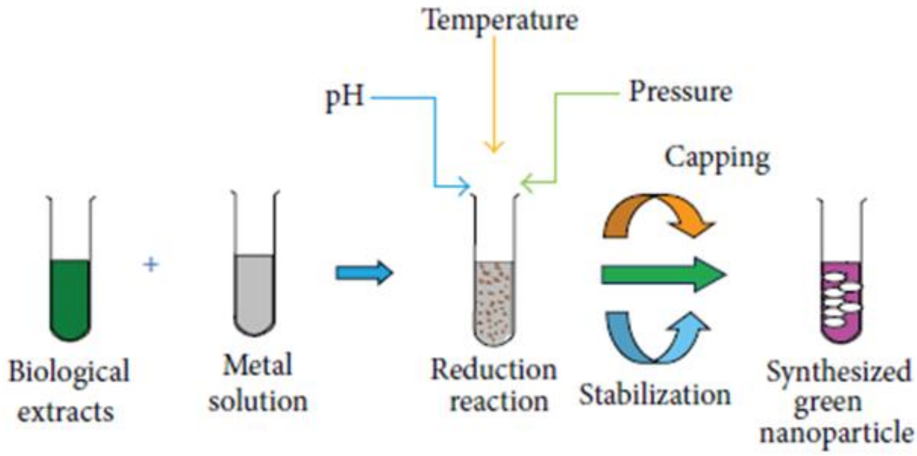
Characterization of Nanoparticles

The synthesized nanoparticles are examined using various spectroscopic and microscopic techniques: UV-visible spectroscopy (UV-vis), dynamic light scattering (DLS), atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), powder X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FT-IR), and Raman spectroscopy.

The most common metallic nanoparticles synthesized using bacteria includes NPs of Pd, Ag, Au and metal oxides like ZnO.

The optimization of culture conditions such as nutrients, light, medium pH, temperature, mixing speed, and buffer strength significantly affects the stability and size of synthesized NPs. (Iravani, 2011; Mukherjee, et al. 2001).

Despite extensive research, a complete understanding of nanoparticle synthesis mechanism occurring in microorganisms is still in its developing stage because each type of microorganism tends to behave and interact differently with particular metallic ions.



Source: (Patra and Baek, 2014)
Figure 4: Nanoparticle synthesis using Microorganisms: A green Approach

Applications of Nanoparticles

Noble nanoparticles in the recent years had attracted much attention and possess incredible applications in the field of biology, medicine and electronics. Out of several synthesis methods such as physical and chemical, biological method has been widely accepted because of reliability, simplicity, non toxicity and environment friendly procedure.

The combination of nanotechnology and green chemistry unfolded the different options of biologically and cytologically compatible metallic nanoparticles. In ancient Indian Ayurvedic medicine book " Charak Samhita " the therapeutic potentials of various metals are mentioned in details stating the use of silver as earlier as 300 BC. Among the different nanoparticles, silver nanoparticles (AgNPs) has been widely used because of its applicability in biomedical, drug delivery, water treatment, Agricultural, electronic devises, adhesives etc. (Sista et al., 2016) (Velusamy et al., 2016)

Because of the special characteristics of the AgNPs, it possesses wide applications as anti-microbial, anti-parasitic and anti-fouling agents; it can also be used as an agent for site-specific medication, water purification systems, etc. The mechanism through which AgNPs act on bacteria is complex and not widely studied and explained hypothetically. AgNPs act on microbes by two mechanisms namely: Inhibitory action and bactericidal action. AgNPs possess antibacterial action against both gram positive and gram negative bacteria but the reports are contradictory by different researchers and not yet confirmed. (Sista et al., 2016)

AgNPs also possess specific applications in the field of biomedical sciences such as, topical antimicrobial gel formulation , AgNP based dressings for wound healing, orthopedic applications, medical catheters, blood contacting implants, endodontic filling materials, dental instruments, and coating of contact lenses. (P. Sathishkumar et al., 2018)

Nanotechnology can also plays an magnificent role in targeted drug delivery therapy in medicinal field because of its unique feature of changing physical chemical and biological properties with respect to surface: volume of its target. Silver Nano particles can also be used as a therapeutic and diagnostic tool in the field of advanced medicinal invention like drug delivery, anticancer agents, and for developing anticancer drugs. And as per Ruoslahti et al. 2014 if proven the effective advancement of penetrating and targeting tumor cells, then this new development can also help in the treatment of several other disorders such as : neurological defects , diabetes, osteoporosis, Alzheimer's disease, Parkinson's disease, cardio vascular disease, tuberculosis, tumor etc.. (Gupta et al., 2017)

Nanotechnology is also hypothesized to play key role in cancer diagnosis at early stage through visualization of cancer cells at molecular level. It can also help in finding out precise location of tumor and to rule out expression and activity of specific molecules influencing tumor behavior and its therapeutic response (Gobo et al., 2015).

Apart from silver, other metallic nanoparticles of noble metals such as gold, platinum, and palladium have also been widely used in products ranging from cosmetic to medical and pharmaceutical science. Gold nanoparticles have been extensively used in biomedical applications, separation sciences, disease diagnostics, and pharmaceuticals.

Platinum nanoparticles have been widely used in biomedical applications in either pure form or alloyed with other nanoparticles. (Shah et al., 2015)

Palladium nanoparticles are used in catalysis and electro-catalysis applications, chemical sensors, optoelectronics, and anti-bacterial applications.

Other non-noble metallic nanoparticles such as iron , copper , zinc oxide , and selenium have also been used in medical treatments, cosmetic formulations, and anti-bacterial applications. (Shah et al., 2015)

Recent study on CeO_2-NPs reported that it possess significant antibacterial property towards both gram-negative and gram-positive bacteria. It is also found to be beneficial in therapy for neurodegenerative diseases by reducing ROS production. (Fahimeh et al., 2017)

III. Conclusion

The field of nanobiotechnology is very dynamic and biosynthesis of nanoparticles using different microorganisms and plants is the focused area of current research. The biosynthesis of nanoparticles is a cost-effective and environmentally friendly alternative to chemical and physical methods. Plant-mediated synthesis of nanoparticles is a green chemistry approach that connects nanotechnology with plants and provides a sustainable, resource efficient and cheap method of synthesis. Biosynthesis of nanoparticles has a great potential as in nanoparticles production as this methods is free from toxic and hazardous chemicals used in conventional physical and chemical methods and is less expensive. Nanoparticles find applications in biology, medical sciences, drug delivery, and electronics to name a few.

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