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A CRITICAL REVIEW ON NANOPARTICLES SYNTHESIS: PHYSICAL, CHEMICAL AND BIOLOGICAL PERSPECTIVES

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Abstract: A nanoparticle is a tiny particle with a size between one to one hundred nanometers. Due to their small size, these are not visible by the naked eye and exhibit enhanced properties such as high reactivity, strength, sensitivity, stability, surface area, etc. Comparatively, to their larger material equivalents, nanoparticles can display significantly highly advantageous physical, chemical, and medicinal properties in order to protect human life. Nanotechnology has emerged as a prominent multifaceted field in the past few years, with potential applications in the medicinal products sustainability of the environment, agriculture, industries and remediation of pollution domains. Nanoparticles are synthesized by using a variety of methods. Traditionally, physicochemical methods have resulted in concerns regarding the environment as they reduce metal ions, which is followed by surface modification, the addition of toxic compounds for stability, and the resulting generation of deleterious byproducts. Reducing and stabilizing agents are required for synthesizing nanoparticles by using chemical, physical and biological procedures at ambient temperature and pressure. Different physical, chemical and green synthesis methods were used to synthesize nanoparticles. Ball milling, melting, pulsed laser ablation, and pulsed wire discharge technology are examples of physical approaches. Different plant root, stem, and leaf sections, as well as bacteria, fungi, and yeast, were used in herbal approaches as well as a polyol, micro-emulsion, and inert gas condensation to create nanoparticles. The nanoparticles are synthesized by using two approaches like top-down approach and the bottom-up approach. This review expresses the formulations about chemical, physical and green synthesis of nanoparticles.

Index Terms **Nanoparticles, Nanotechnology, Physical synthesis, Chemical synthesis, Green synthesis method**

1. INTRODUCTION

The umbrella term "nanotechnology" refers to branches of science and engineering wherein structures, devices, systems, and materials are designed, characterized, produced, and utilized. Nanoscale phenomena are used in this context. The nanoparticles can be categorized into several categories, comprising inorganic, organic, ceramic, and carbon-based nanoparticles. The inorganic nanoparticles are further classified into metal nanoparticles and metal oxide nanoparticles. The carbon-based nanoparticles are classified into Fullerene, Carbon nanotubes, Graphene, Carbon nanofiber and Carbon Black Nanoparticles(CBNP) and can also be categorized on the basis of dimensions such as one, two, and three-dimensional nanoparticles.

Metal nanoparticles can be produced using a variety of methodologies. Synthesis procedures that use top-down and bottom-up approaches have been identified. Top-down processes include quenching, constant milling, and lithography. The aforementioned method cannot effectively control particle size and structure. Scientists mostly use a bottom-up approach to synthesis nanoparticles, which involves building a material up from the fundamental basis, atom by atom, molecule by molecule, and cluster by cluster[1,2].

The physical synthesis of nanomaterials involves the utilization of deposition, sputtering, ball milling, and plasma-based techniques[3]. The majority of these methods only gradually create metal nanoparticles. For instance, a ball milling method's yield of nanomaterials is 50% or less[4]. In the case of sputtering, which results in a wide particle size distribution, only 6-8 percent of the sputtered material is predicted to be less than 100 nm. It takes a lot of energy to use plasma and laser ablation techniques. Due to their wide size distribution, sluggish manufacturing rate, waste by-products, and high energy consumption, the majority of physical processes are extremely expensive and cannot be employed for practical, commercial purposes[5].

Chemical reducers in solvents (aqueous and non-aqueous) have been proven to be effective in producing colloidal metal nanoparticles from a variety of precursors. The electrochemical approach[6], sono-chemical method[7], radiolytic method[8], and photochemical method[9] are among several of the chemical techniques that have been explored.

2. METHODS OF SYNTHESIS OF NANOPARTICLES

Nanoparticles can be synthesized through various methods, each tailored to produce particles of specific size, shape, and composition. One common approach is chemical reduction, which involves the controlled reduction of metal ions in solution to form nanoparticles. Another widely employed technique is the sol-gel method, where a precursor solution undergoes hydrolysis and condensation reactions to create nanoparticles within a gel matrix. Physical methods, such as laser ablation and ball milling, can also produce nanoparticles by breaking down bulk materials into nanoscale particles. Additionally, biological methods utilize microorganisms or enzymes to synthesize nanoparticles, a process known as biogenic synthesis (Fig. 1).

2.1 Top-down synthesis

Initially, macro structures are used in the top-down approach. The techniques begin by using an external force to reduce larger solid materials into smaller fragments. This method uses a variety of physical, chemical, and thermal approaches to supply the energy needed for nanoparticle fabrication.

The main disadvantages of these systems are their cost-prohibitive setup and necessity of large installations. The methods are quite expensive and aren't suitable for mass production. The approach is suitable for laboratory testing. The approach is based on the processing of materials and cannot be employed on sensitive specimens[10,11].

Top-down approach includes:

1. Physical vapor deposition.
2. Chemical vapor deposition.
3. Ion implantation.
4. Electron beam lithography.
5. X-ray lithography.

2.2 Bottom-up synthesis:

In this technique, nanoparticles are created from smaller building blocks like molecules and atoms via a range of chemical and biological processes, or by self-assembling atoms into new nuclei that eventually grow into a particle with nanoscopic dimensions.

Bottom-up techniques include[13]:

1. Sol-gel synthesis
2. Colloidal precipitation
3. Hydrothermal synthesis
4. Organometallic chemical route
5. Electrodeposition

Other methods can be classified into three categories based on these two above mentioned fundamental concepts:

1. Physical method
2. Chemical method
3. Green/Herbal method

2.1.1 PHYSICAL METHODS:

Physical methods of nanoparticle synthesis involve the creation of nanoparticles through various physical processes that manipulate matter at the nanoscale. These methods offer precise control over particle size, shape, and composition. Some common physical methods include:

(i) Mechanical/high ball milling technique

Milling is a solid-state processing technique used to produce nanoparticles. The milling process uses raw materials that are smaller than a micron to undergo a multitude of changes. The production of nanoparticles can be done with a variety of mechanical mills that are both affordable and easily accessible. Depending on their abilities and intended applications, these mills can be classified into various groups. These processes can produce ultra-fine particles, however doing so is highly difficult or takes a very long time because of mechanical limitations.

However, the main advantages of mechanical milling are its simplicity, low cost of nanoparticle production, and capacity for large-scale production. Significant elements that determine the final product's quality include the types of mill, milling speed, container, time duration, temperature, size and size distribution of the grinding medium, process control agent, weight ratio of balls to powder, and the volume of vial filling[14,15].

Nanoparticles are produced by mixing streams of molten metal with turbulence. Nanoparticles are contained in a glass. Glass is an amorphous substance with crooked molecular or atomic symmetry. Rapid cooling of metals can result in the formation of metallic glasses and amorphous solids. Examples include the synthesis of TiB_2 nanoparticles from heated Ti and molten Cu-B[16,17].

(ii) Chemical Vapor Deposition

The substrate is coated with a thin layer of a gaseous reactant at temperatures between 300 °C and 1200 °C. A thin film of product is produced on the surface of the heated substrate as a result of a chemical reaction between the heated substrate and the combining gas. Between 100 and 105 Pa has been employed as the pressure. There are various CVD varieties, including Plasma Enhanced CVD, Atomic Layer Epitaxy, Vapor Phase Epitaxy, and Metallo-Organic CVD. This method has the benefit of making stiff, homogeneous, potent, and extremely pure nanoparticles. To be eliminated from the substrate, the by-products must be returned to the gaseous phase.

There are two approaches to heat substrates: cold walls and hot walls. Even the reactor walls are susceptible to deposition in the hot wall layout. This can be avoided if a cold wall is used. The final two factors that influence growth rate and film quality are the pressure of gases and substrate temperature[18,19].

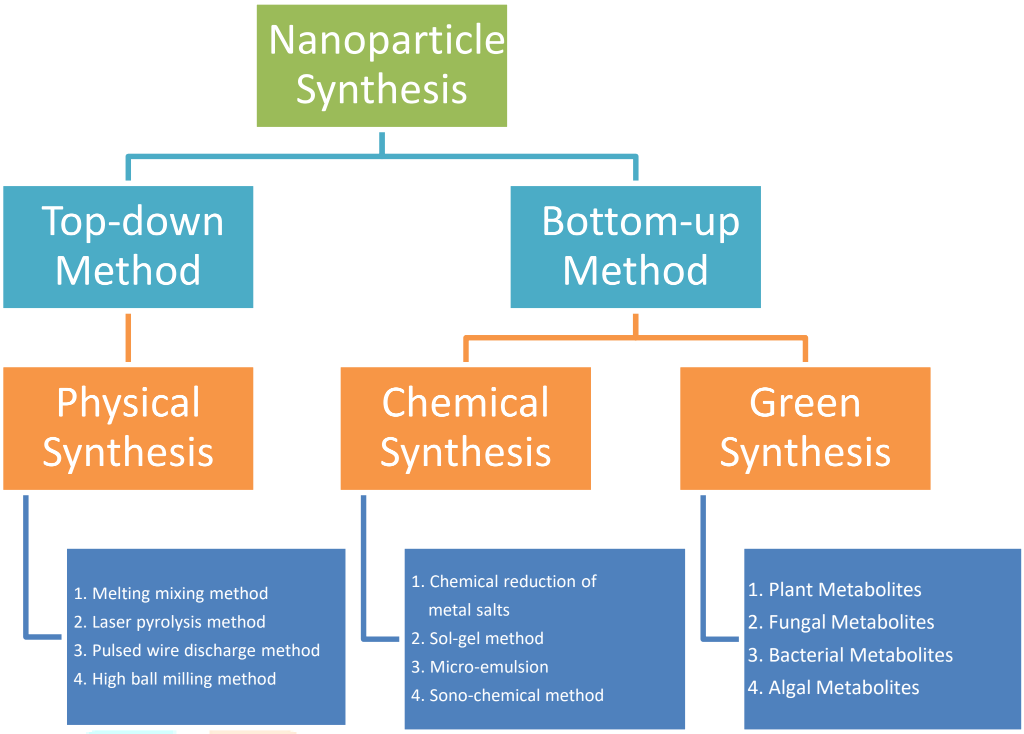

Fig.1: Numerous methods of Nanoparticles synthesis

(iii) Laser Pyrolysis

Laser pyrolysis is a method of using a laser to produce nanoparticles. When an inert gas, such as helium or argon, is present, a powerful laser beam is focused to disintegrate the mixture of reactant gases. The particle size and distribution are significantly influenced by the gas pressure[20].

(iv) Ionized Cluster Beam Deposition

The main objective of this method is to form a single-crystalline thin film. The system consists of an evaporation source, a nozzle that allows material to expand into the chamber, a cluster-accelerator, an electron beam that ionizes the clusters, and a substrate that can be coated with nanoparticles. After coming into touch with an electron beam, collections get ionized. Because of the hastening voltage used, the clusters are localized close to the substrate.

Stable clusters of some materials would prefer to stay as small as clusters of particles because doing so would require a lot of energy. However, the energy with which the clusters strike the substrate can be controlled by monitoring the accelerating voltage. An ionized cluster beam can therefore be used to produce nano-crystalline material sheets[21].

(v) Pulsed laser ablation

In this method, a target in the material is attacked by a high-power pulsed laser beam that has been focused inside a vacuum chamber. Next, plasma is generated, which is later transformed into a colloidal solution of nanoparticles. The majority of the time, the nanoparticles are prepared using Second Harmonic Generation (ND: YAG type) lasers. The type of laser, the number of pulses, the pulsing time, and the type of solvent are a few variables that influence the results[22,23].

(vi) Mechanical chemical synthesis

Mechanical energy is employed to start chemical reactions during this process of mechanical chemical synthesis. Metals, oxides, and chlorides are the main chemical building blocks that interact during milling or a subsequent heat treatment to produce a composite powder with ultrafine particles dispersed in a stable salt matrix. After the matrix has been removed, these ultrafine particles can be retrieved by washing with an appropriate solvent[22].

(vii) Pulsed wire discharge method

Nanoparticles are produced physically via pulsed wire discharge (PWD). Unlike any of the other methods described earlier, the PWD method employs a completely distinct mechanism to generate metal nanoparticles. PWD produces nanoparticles by evaporating a metal wire using a pulsed current and cooling the resulting vapour with surrounding gas. Metal, oxide, and nitride nanoparticles have been reported to be produced using PWD; this method might provide a high production rate and good energy efficiency. Due to the high price and inability to be applied precisely for different metals, this method is not frequently employed in common industrial applications. It is especially advantageous for high electrical conductivity metals that are easily accessible in the form of small wires[24].

(viii) Thermal decomposition method

Heat triggers chemical breakdown in this endothermic reaction. The chemical bond of the molecule is harmed by this heat. The decomposition temperature is the point at which an element begins to chemically break down. The breakdown of the metal at a specific temperature produces the nanoparticles[25].

(ix) Lithographic methods

Top-down, lithographic methods can produce the bulk of micron-sized features, but they are resource and equipment-intensive. Lithography has been used to make printed circuit boards and computers for more than ten years. Nano imprint lithography is a subset of lithography that differs from traditional lithography. In many aspects, it is similar to template synthesis. Soft polymeric material is first stamped onto a template to make a pattern. Top-down production methods are used to create stamped materials. Using latex spheres, nanosphere lithography produces templated matrices. There are many different types of lithography methods, such as photolithography, electron beam lithography, soft lithography, focused ion lithography, nano-imprint lithography, and dip pen lithography[26].

(x) Laser ablation

Laser ablation synthesis in solution is a simple method for the creation of nanoparticles from different solvents. A laser beam is used to irradiate various metals submerged in fluids, condensing a plasma to produce nanoparticles. This top-down method, as opposed to conventional chemical processes, is very beneficial in the production of metal nanoparticles. Without using any chemicals or stabilizing agents, the stable nanoparticles can be made using laser ablation procedures[27].

(xi) Sputtering

Nanoparticles are deposited by way of particle ejection from the phenomenon known as sputtering[28]. For the deposition of nanoparticles in thin layers, annealing is immensely beneficial. The dimensions and shape of nanoparticles are determined by the factors such as temperature, coating thickness, time of annealing and substrate[29].

(xii) Spinning

Nanoparticles are produced through spinning. Using a spinning disc reactor, the nanoparticles are produced. The hydrolysis, condensation, and calcination of crystalline anatase, rutile, and brookite TiO_2 nanoparticles were carried out using the sol-gel technique.

Spinning disc reactor (SDR) is a device with a rotating disc that allows physical parameters, like temperature, to be controlled. To stop chemical reactions and remove oxygen, the reactor is filled with nitrogen or another inert gas. A liquid, such as water or a precursor, is injected into the chamber or reactor. A number of factors, such as disc surface, liquid to precursor ratio, disc rotation speed, liquid flow rate, and feed position, affect the characteristics of nanoparticles made by SDR[30]. Spinning techniques for creating nanoparticles are following-

A) Fusion of atoms or molecules brought on by spinning
B) Precipitation
C) Collection
D) Drying

(xiii) Pyrolysis

The most popular commercial process for making nanoparticles is pyrolysis. The precursor is burned during this process utilizing flame. The precursor may be liquid or in a gaseous condition. To create the nanoparticles, the precursor is put into the furnace at a high pressure[31]. Sometimes lasers or plasma are used to generate a high temperature rather than a flame. High temperatures cause easy evaporation[32]. Pyrolysis method is quite beneficial as it is effective, affordable, straightforward, continuous processes with high yields.

(xiv) Plasma

Plasma is produced via radio frequency (RF) heating coils. A pestle containing the first metal is placed inside of an airtight chamber after being sealed. The metal is then heated above its evaporation point using high voltage RF coils encircling the evacuated chamber. After flowing into the system, the procedure's primary gas, helium, produces a high-temperature plasma near the coils[33]. The classification of plasma techniques depends on reactor material feeding and heating source (electrodeless/containing electrodes).

(xv) Microwave irradiation

Microwave irradiation is a synthesis technique that has been widely used in the synthesis of organic, inorganic, and inorganic-organic hybrid materials due to its well-known advantages over conventional synthetic methods[34]. A study was done on the new phase transfer oxidative agent CTAMABC to see how quickly and effectively it could oxidize organic molecules in microwave conditions. A fast addition of an alcohol (0.5-1.5 m mole in 0.5-1.5 ml of acetonitrile) was made to a suspension of CTMABC (1 m mole) in acetonitrile (2 ml), and the resulting mixture was vigorously agitated. After that, microwave radiation was used to irradiate the combination (3.67 GHz, 300 W). Prior to the precipitation of the black-brown reduced reagent, the solution briefly became homogenous.

To track the development of reactions, thin layer chromatography (TLC) and a UV/VIS spectrophotometer (at 352 nm) were employed[35]. In a different experiment, ethanol was used to dissolve anthranillic acid (1.37 g, 0.01 mole) and o-phenylenediamine (1.08 g, 0.01 mole) (15 ml). K_2CO_3 was also added to the mixture, which was then placed in a microwave oven and heated to reflux for 10 minutes at power (140 Watt). TLC was utilized to keep track of the response. After the reaction was finished, the ethanol was removed using distillation, and the remaining material was added to crushed ice. After that, 10% NaOH was added to the process to make it alkaline and produce a solid byproduct. From ethanol, the substance was filtered, dried, and recrystallized[36].

(xvi) Gamma Radiation

Gamma radiation is the preferred method for producing metallic nanoparticles because it is repeatable, allows for shaping of the particles, produces monodisperse metallic nanoparticles, is simple, inexpensive, uses fewer toxic precursors (one-pot reaction), uses the least amount of reagents, and uses reaction temperatures that are close to room temperature. It has been demonstrated that radiolytic reduction is an effective method for creating monosized and widely scattered metallic clusters[37]. The excitation and ionization of the solvent are the main outcomes of the interaction of high-energy gamma rays with a solution of metal ions[38]. According to Abidi and Remita (2010)[38] provide a thorough explanation of the various reactions in their work. According to the equation that follows, water can specifically be produced by irradiating a number of reducing and oxidizing substances:

$$H2O \longrightarrow e^-_{aq},\ H_3O^+,\ H\bullet,\ OH\bullet,\ H_2,\ H_2O_2$$

The reducing agents e^-_{aq} and H• are essential to the process of creating metallic nanoparticles from metallic salt solutions.

Unfortunately, hydroxyl radical generation OH• reduces efficiency unless some particular hydroxyl scavengers are applied. Isopropanol is one of them that is widely used[39]. With the intention of examining their plasmonic absorption band, UV-Visible spectroscopy was used to further explore the solutions of MNP, predominantly gold and silver, that were created using this procedure[40,41]. Additionally, MNP was trapped by irradiation inside polymers or porous frameworks, such as mesoporous silica[42-44].

2.2.1 CHEMICAL SYNTHESIS

Chemical methods of nanoparticle synthesis involve the creation of nanoparticles through chemical reactions, typically in solution. These methods are widely used because they offer precise control over nanoparticle size, shape, composition, and surface properties. Some common chemical methods include:

(i) Chemical reduction method

Chemical reduction is a productive wet-chemical method for the synthesis of zero-valent nanoparticles. It is based on chemically reducing aqueous salts of metals, such as silver nitrate (AgNO3) in the case of the production of silver nanoparticles. In order to decrease the precursor metal salt, at least one reducing agent is used to provide metal ions electrons, reducing them to the zero-valent state. Reductants often utilized include ascorbate, citrate, and boron hydride. Reduction in nanoparticle size is stabilized by a stabilizing agent.

Cetyltrimethylammonium bromide [$(C_{16}H_{33})$ $N(CH_3)_3Br$; CTAB], which is frequently used in the manufacture of gold nanoparticles, is an illustration of a stabilizing agent. When creating silver nanoparticles, the stabilizing agents could also be the reducing agents themselves, like sodium citrate[45].

(ii) Micro Emulsion

Micro-emulsions which are an isotropic and thermodynamically stable mixture of oil, water, surfactant, or in combination with a co-surfactant, are a common technique for creating nanoparticles. The two main categories of micro-emulsions are the Direct method (oil dispersed in water) and reverse micro-emulsions are the two fundamental varieties (water dispersed in oil). Salts and/or other components may be present in the microscopic aqueous phase drops (micelles), and the surfactant combination may really constitute the "oil" in some cases. When micelles mix, a reaction to produce nanoparticles can also occur, and the surfactants in "oil" regulate the formation of the nanoparticles[46].

(iii) Sol-Gel Method

Metal alkoxides or metal precursors in solution are condensed, hydrolyzed, and thermally reduced**.** The result is the formation of a stable solution, or sol. The gel's viscosity increases as a result of hydrolysis or condensation. By adjusting the precursor concentration, temperature, and pH levels, the particle size can be observed. It may take several days for the solvent to be removed, for Ostwald ripening to occur, and for the phase to change, but this mature step is necessary to enable the growth of solid mass[47].

(iv) Sonochemical Synthesis

Sonochemical fusion of copper salt and palladium salt successfully produces Pd-CuO nanohybrids. By employing ultrasonic waves and palladium, switch metal salts may be transformed into their oxides. Palladium is either found as palladium salts or as the pure metallic element Pd[48,49].

(v) Co-Precipitation Method

It is a solvent displacement method and is a wet chemical procedure. Examples of polymer solvents include ethanol, acetone, hexane, and non-solvent polymers. Phases of polymers might be man-made or natural. Fast propagation of the polymer-solvent into the polymer's non-solvent phase can be accomplished by adding the polymer solution last to the mixture. Nanoparticles are formed when there is interfacial stress between two phases[50,51].

(vi) Inert Gas Condensation Method

This approach enables the mass production of metal nanoparticles. The inactive gas compression method, which produces nanoparticles by causing a metallic source to disappear in an inert gas, has been widely used to build fine nanoparticles. Metals evaporate at a reasonable rate at a temperature that is feasible. Copper metal is vaporized in an argon, helium, or neon-filled container to produce copper metal nanoparticles. After the atom boils out, its energy is rapidly lost by cooling it with an inert gas. Gases are cooled using liquid nitrogen to produce nanoparticles between 2 and 100 nm in size[52].

(vii) Hydrothermal Synthesis

It is one of the methods for producing nanoparticles that is most often used. It is one of the approaches to synthesize nanoparticles that have been utilized most frequently and is primarily based on chemical reactions. For the synthesis of nanoparticles, hydrothermal synthesis uses a wide temperature range from room temperature to extremely high temperatures. Comparing this strategy to physical and biological ones has a number of benefits. At higher temperature ranges, hydrothermal synthesis-produced nanomaterials might become unstable[53].

(viii) The Polyol Method

The polyol technique is a natural method to make nanoparticles. In this process, the nonaqueous liquid polyol serves as both a solvent and a reducing agent. The nonaqueous solvents used in this approach have the advantage of minimizing surface oxidation and aggregation. This method makes it possible to simply adjust the size, texture, and form of nanoparticles. The polyol method is additionally feasible to produce nanoparticles on a large scale[54]. If the synthesis is carried out at a modestly elevated temperature with precise particle growth control, the polyol process can be regarded as a sol-gel approach in the synthesis of oxide[55]. Y_2O_3, V_xO_y, Mn_3O_4, ZnO, $CoTiO_3$, SnO_2, PbO, and TiO_2 are only a few of the oxide sub-micrometer particles that have been the subject of studies on the production of oxide particles[56-63].

The solvent that is usually utilized in the polyol technique to synthesize metal oxide nanoparticles is ethylene glycol due to its strong reducing ability, high dielectric constant, and high boiling point. Additionally, metal ions can be linked with ethylene glycol to create metal glycolate, which then causes oligomerization[64]. According to a study, as-produced glycolate precursors can be calcined in air while retaining their original precursor shape, resulting in their more prevalent metal oxide derivatives[55]. The synthesis of core-shell nanoparticles and bimetallic alloys has also been done using the polyol synthesis method[65-67].

Kim et.al.[68] used the polyol method to produce icosahedral and cubic gold particles on the order of 100-300 nm by meticulously regulating the growth rate for each crystallographic orientation[68]. Silver nitrate and PVP can be mixed in different proportions to produce a wide range of regulated morphologies, such as nano-cubes and nanowires as reported by Xia and colleagues[69].

2.2.2. GREEN SYNTHESIS

The traditional methods for producing NPs include ultrasonication, radiolysis, microwave, spray pyrolysis, electro spinning, the sol-gel method, chemical reduction, and inert condensation. However, the urgent need for a procedure that is quicker, cheaper, more productive, non-toxic, and environmentally friendly has turned attention to greener methods. The stabilization of NPs is effectively aided by biogenic sources such as bacteria, fungi, and other plant parts. In the green production of NPs, bacteria, yeast, and fungi are utilized because the process may be adjusted by changing the culture parameters, such as nutrition, pH, pressure, and temperature[70] (Fig. 2.).

(i) Synthesis from plants

A number of plant metabolites, including terpenoids, alkaloids, sugars, proteins, etc., are crucial in the bioreduction of metal ions to produce metallic nanoparticles. Secondary metabolites include a polyhydroxy group, and this polyhydroxy group is what gives them their antioxidant properties. By lowering metal ions, it also limits the creation of nanoparticles. Three crucial phases are involved in the method by which metal nanoparticles are formed utilizing plant extract[70]:

- **First phase**: This phase is referred to as the activation phase. Metal ions undergo reduction during this phase. In this phase, the reduced metal ions also start to form crystals.
- **Second phase:** This phase is referred to as the growth phase. Nanoparticles increase at this period. Ostwald ripening is a process that causes small nanoparticles to combine into larger ones. The thermodynamic stability of nanoparticles is increasing at this stage.
- **Third phase:** The termination phase is the third phase. The final nanoparticle's shape is decided during this phase. Nanoparticles are the most stable at this stage. In the second phase, known as the growth phase, the corresponding nanoparticles cluster and take on various irregular shapes, such as nanoprisms, nanotubes, and so on.

Bio-Reduction Mechanism

- **Silver:** AgNO3 combines with plant extract to create nanoparticles in the manner described below.

$$Ag^{+}NO^{-}_{3} + \text{Plant Extract} \longrightarrow \text{AgNPs} + \text{byproducts}$$

- **Gold:** Au+ ions interact with a variety of biomolecules, including proteins, enzymes, amino acids, and carbohydrates. These metabolites transform metallic Au° nanoparticles from Au+ ions. Following is the reaction's progression:

$$HAu^{+}Cl_{4}.4H_{2}O + \text{Plant Extracts} \longrightarrow \text{AuNPs} + \text{byproducts}$$

- **Platinum:** The following reaction is used to create platinum nanoparticles:

$$H_{2}Pt^{+}Cl_{2}.6H_{2}O + \text{Plant Extracts} \longrightarrow \text{PtNPs} + \text{byproducts}$$

- **Copper:** Using herbal extract, the following reduction reaction can be used to create copper nanoparticles:

$$CuSO_{4}.5H_{2}O + \text{Plant Metabolites} \longrightarrow \text{CuNPs} + \text{byproducts}$$

- **Zinc:** similarly, Zn nanoparticles can be synthesized by following reaction:

$$\text{Zinc Nitrate} + \text{Plant Extract} \longrightarrow \text{ZnO} + \text{byproducts}$$

(ii) Synthesis from Fungi:

It has been noted that extracellular and intracellular enzymes found in cells are used mostly by fungi in the creation of NPs. Studies suggested that the synthesis of metallic NPs was carried out by enzymes such as nicotinamide adenine dinucleotide (NADH)-dependent reductase.

Studies have shown that enzymes like nicotinamide adenine dinucleotide (NADH)-dependent reductase were responsible for the synthesis of metallic NPs. The output of NPs is typically higher in fungi than in bacterial cells because they have more biomass present. Although bacteria are more frequently used to make metallic NPs, the presence of mycelium in fungi may make them more useful since they offer a larger surface area for interactions. Because fungus produce more enzymes than bacteria do, the process of turning metallic salts into metallic NPs happens more quickly. The mechanism of metal ion absorption and reduction for the generation of NPs involved the fungal cell wall significantly as well. The formation of the nanoparticle depends heavily on the components of fungal cells, including the cell wall, cell membrane, protein, enzymes, and other intracellular components. Temperature, pH, biomass, and other physical conditions are among the variables that affect how metallic NPs like AgNPs are created. These nanoparticles' varied features, particularly their antimicrobial (antibacterial, antifungal, and antiviral) activity, have been shown to be beneficial for human welfare. In actuality, the manufacture of AgNPs by fungus or materials derived from fungi does not necessitate the use of any harmful substances during the NP recovery and purification process[71,72]. Drawbacks of the fungi-mediated NPs synthesis include higher production costs and longer biosynthesis times[73].

(iii) Synthesis from Bacteria:

Bacteria exhibit a remarkable ability to reduce heavy metal ions, making them one of the best candidates for nanoparticle synthesis. As an illustration, certain bacterial species have figured out how to use specific defensive mechanisms to resist off stresses like the toxicity of heavy metal ions or metals. *Pseudomonas stutzeri* and *Pseudomonas aeruginosa* are the two examples of those that have been demonstrated to be able to grow and survive even in situations with high metal ion concentrations. Bacterial cells are capable of binding substantial amounts of metallic cations.

Furthermore, some of these bacteria have the ability to manufacture inorganic materials, such as the magneto-tactic bacteria that create intracellular magnetite nanoparticles[74]. The microbial system has an intrinsic mechanism for converting metallic salts into nanoparticles (NPs). Studies have shown that the conversion of heavy metals into metallic NPs requires the presence of bacterial organisms. A number of interconnected mechanisms present inside bacterial cells are used to produce the metallic NPs. Another advantage of utilizing bacteria is that they can produce sustainable nanoparticles in large quantities[75,76].

(iv) Synthesis from Algae

Algae are referred to as "bionanofactories" among biological materials since both the live and the dead dried biomass were employed for the synthesis of metallic nanoparticles. A number of algae, including *Lyngbya majuscule, Spirulina platensis*, and *Chlorella vulgaris*, were employed to create silver nanoparticles at a low cost. Different groups of algae, including diatoms and euglenoids as well as Chlorophyceae, Phaeophyceae, Cyanophyceae, and Rhodophyceae, have been employed in the production of metallic NPs. Algae are the best candidate for the biogenesis of nanoparticles due to their capacity to accumulate metals and decrease metal ions. Metallic NPs fabricated from various algal sources used a multidisciplinary approach resulting from the investigational use of NPs in biological systems[77].

Three crucial steps can be taken to create nanoparticles from algae:

(i) Preparing the algal extract in water or an organic solvent by heating or boiling it for a predetermined amount of time;

(ii) Creating molar solutions of ionic metallic compounds; and

(iii) Incubating the algal solutions and molar solutions of ionic metallic compounds either continuously or intermittently for a predetermined amount of time under controlled conditions.

The production of NPs is dose-dependent and depends on the kind of algae employed. The reduction of metals is carried out by a number of biomolecules, including pigments, peptides, and polysaccharides. Proteins use amino groups or cysteine residues to stabilize and cap the metal nanoparticles in aqueous solutions. Algae are used to synthesize nanoparticles, which takes a lot less time than other biosynthetic processes. *Sargassum wightii* and *Fucus vesiculosus* are two seaweeds that have been employed to create AgNPs of various sizes and forms thus far. Weakly investigated marine algae are used to synthesize NPs. In addition to seaweeds, microalgae like diatoms (*N. atomus* and *D. gallica*) may produce gold, silica-gold bio-nanocomposites, and gold nanoparticles.

CONCLUSION

The beneficial aspects of using physical methods include the absence of the use of toxic chemicals, purity, consistent size, and shape, while its disadvantages are high cost, radiation exposure, high temperature, and decreased productivity. Chemical methods have the advantage of producing nanoparticles relatively quickly, but they also have the disadvantage of being highly expensive and generating dangerous, poisonous, and damaging compounds that pose a range of environmental risks. Nanoparticle synthesis with herbal reagents is an economical, safe, non-toxic, and environmentally friendly process that also produces nanoparticles with increased stability. Future research is anticipated to emphasize on developing nanoparticles with minimal potential toxicology and with the greatest possible antimicrobial properties. The fabrication of metallic nanoparticles, specifically by non-toxic green synthesis techniques, is of the utmost significance as they are utilized in many different kinds of applications, involving the treatment of cancer, the administration of drugs, and the production of biosensors. With available methods, it is equally essential to further develop and innovative the approaches to optimize nano-formulations synthesis methods to bridge the existing knowledge with future technologies such as AI which paves the way for effective applications of nanoparticles.

Our team is actively engaged in exploring green synthesis methods for nanoparticles, which offer the added benefit of sustainability and eco-friendliness. The utilization of biological entities, such as plants or microorganisms, in nanoparticle synthesis holds great promise for environmentally responsible and resource-efficient production, aligning with the global pursuit of greener and more sustainable technologies. Through our ongoing research in green synthesis, we aim to contribute to the development of innovative, eco-conscious approaches for creating nanoparticles with diverse applications and a reduced environmental footprint.

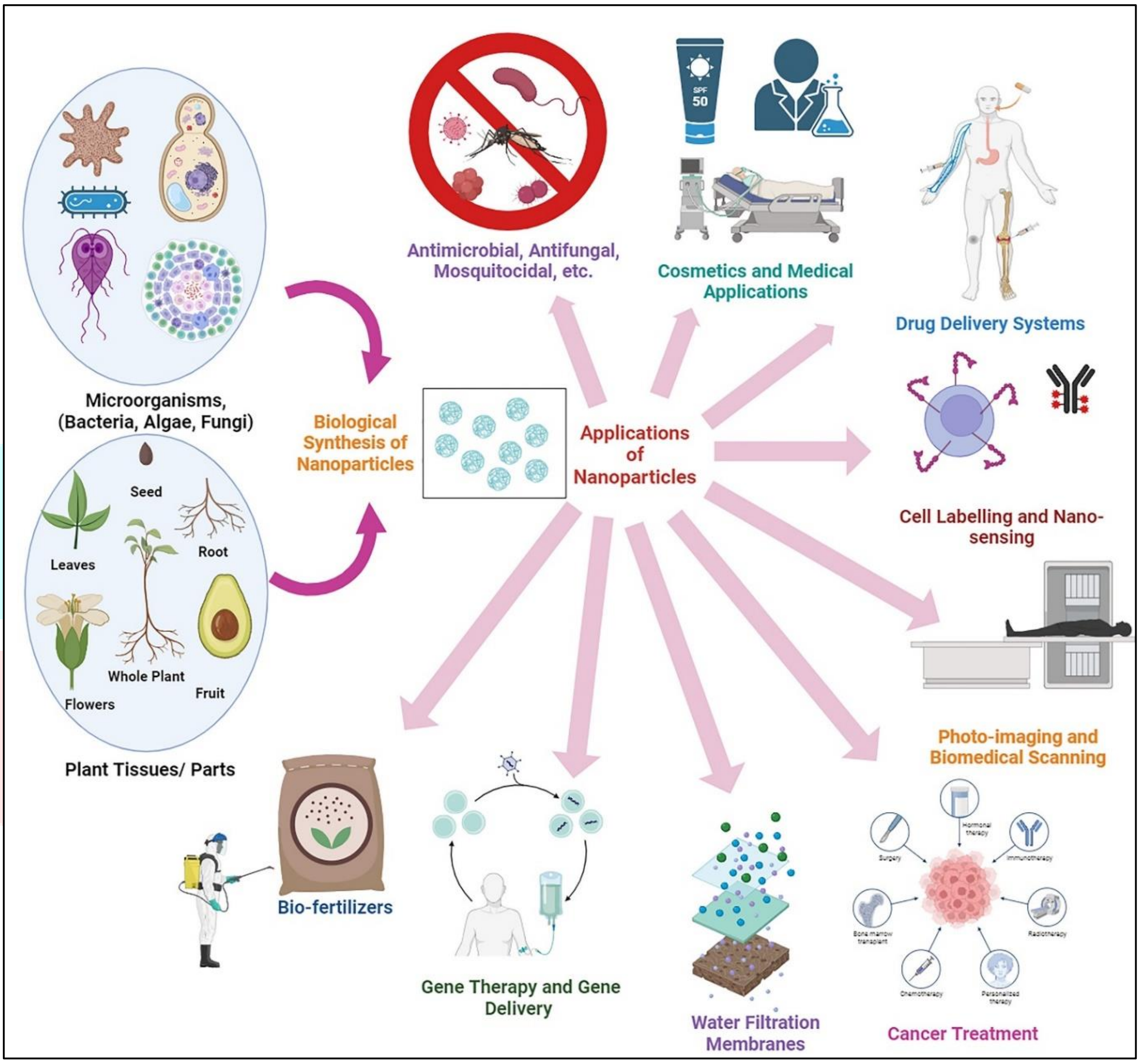

Fig.2: Biological synthesis and applications of nanoparticles.

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REFERENCES:

1. Adlim A. Review: Preparations and application of metal nanoparticles. Indonesian Journal of Chemistry. 2006;6(1):1-10
2. Biswal J. A Study on Synthesis of Silver and Gold Nanoparticles by Employing Gamma Radiation, Their Characterization and Applications. Homi Bhabha National Institute; Department of Chemical Sciences; 2012.
3. Dhand C, Dwivedi N, Loh XJ, Jie Ying AN, Verma NK, Beuerman RW, Lakshminarayanan R, Ramakrishna S, Methods and strategies for the synthesis of diverse nanoparticles and their applications: a comprehensive overview. RSC Adv 5 (2015):105003–105037.
4. Prasad Yadav T, Manohar Yadav R, Pratap Singh D (2012) Mechanical milling: a top down approach for the synthesis of nanomaterials and nanocomposites, Nanosci Nanotechnol 2 (2012):22–48.
5. Seetharaman PK, Chandrasekaran R, Gnanasekar S, Chandrakasan G, Gupta M, Manikandan DB, Sivaperumal S (2018) antimicrobial and larvicidal activity of eco-friendly silver nanoparticles synthesized from endophytic fungi *Phomopsis liquidambaris*. Biocatal Agric Biotechnol 16:22–30
6. Hirsch, T., Zharnikov, M., Shaporenko, A., Stahl, J., Weiss, D., Wolfbeis, O. S., & Mirsky, V. M. (2005). Size-Controlled Electrochemical Synthesis of Metal Nanoparticles on Monomolecular Templates. *Angewandte Chemie International Edition*, *44*(41), 6775-6778.
7. Okitsu, K., Mizukoshi, Y., Yamamoto, T. A., Maeda, Y., & Nagata, Y. (2007). Sonochemical synthesis of gold nanoparticles on chitosan. *Materials Letters*, *61*(16), 3429-3431.
8. Gutierrez, M., & Henglein, A. (1993). Formation of colloidal silver by" push-pull" reduction of silver (1+). *The Journal of Physical Chemistry*, *97*(44), 11368-11370.
9. Sato, T., Onaka, H., & Yonezawa, Y. (1999). Sensitized photoreduction of silver ions in the presence of acetophenone. *Journal of Photochemistry and Photobiology A: Chemistry*, *127*(1-3), 83-87.
10. Siwach, O. P., & Sen, P. (2008). Synthesis and study of fluorescence properties of Cu nanoparticles. *Journal of Nanoparticle Research*, *10*(1), 107-114.
11. Muñoz, J.E., Cervantes, J., Esparza, R. *et al.* Iron nanoparticles produced by high-energy ball milling. *J Nanopart Res* 9, 945–950 (2007).
12. Koch, C. C. (1997). Synthesis of nanostructured materials by mechanical milling: problems and opportunities. *Nanostructured Materials*, *9*(1-8), 13-22.
13. Hou TH, Su CH, Liu WL. Parameters optimization of a nano-particle wet milling process using the Taguchi method, response surface method and genetic algorithm. Powder Technol 2007;173:153-62.
14. Konrad A, Herr U, Tidecks R, Kummer F, Samwer K. Luminescence of bulk and nanocrystalline cubic yttria. J Appl Physics 2001;90:35,16-23.
15. Andrievskii RA. The synthesis and properties of nanocrystalline refractory compounds. Russian Chem Rev 1994;63:411.
16. Rastogi A. A mini-review practice of formulations of nanoparticles. Int J Chem Synthesis Chem Reactions 2017;3:1-7.
17. Dikusar AI, Globa PG, Belevskii SS, Sidel’nikova SP. On limiting rate of dimensional electrodeposition at meso-and nanomaterial manufacturing by template synthesis. Surface Eng Appl Electrochem 2009;45:171-9.

18. Dikusar AI, Globa PG, Belevskii SS, Sidel'nikova SP. On limiting rate of dimensional electrodeposition at meso-and nanomaterial manufacturing by template synthesis. Surface Eng Appl Electrochem 2009;45:171-9.
19. Patil, N., Bhaskar, Rajveer, Vyavhare, Vishal, Dhadge, Rahul, Khaire, Vaishnavi, & Patil, Yogesh (2021). Over View on Methods of Synthesis of Nanoparticles. *International Journal of Current Pharmaceutical Research*, *13*(2), 11-16.
20. Behera S, Nayak PL. *In vitro* antibacterial activity of green synthesized silver nanoparticles using Jamun extract against multiple drug resistant bacteria. World J Nano Sci Technol 2013;2:62-5.
21. Karthikeyan B, Loganathan B. A close look of Au/Pt/Ag nanocomposites using SERS assisted with optical, electrochemical, spectral and theoretical methods. Phys E (Amsterdam Neth) 2013;49:105-10.
22. Winterer, M. And Hahn, H., Metallkd, Z., (2003)" Chemical Vapor Synthesis of Nanocrystalline Powders ", NanoceramicsBy Chemical Vapor Synthesis Vol. 94, 1084-1090.
23. Satyanarayana, T., & Reddy, S. S. (2018). A review on chemical and physical synthesis methods of nanomaterials. *Int. J. Res. Appl. Sci. Eng. Technol*, *6*(1), 2885-2889.
24. Preparation of Nanomaterials-NPTEL- Dr. PallabGhosh
25. Salavati-Niasari, M.; Davar, F.; Mir, N. Synthesis and Characterization of Metallic Copper Nanoparticles via Thermal Decomposition. Polyhedron 2008, 27 (17), 3514–3518.
26. Ijaz, I., Gilani, E., Nazir, A., & Bukhari, A. (2020). Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles. *Green Chemistry Letters and Reviews*, *13*(3), 223-245.
27. Amendola, V.; Meneghetti, M. Laser Ablation Synthesis in Solution and Size Manipulation of Noble Metal Nanoparticles. Phys. Chem. Chem. Phys. 2009, 11 (20), 3805–3821.
28. Shah, P.; Gavrin, A. Synthesis of Nanoparticles Using High-pressure Sputtering for Magnetic Domain Imaging. J. Magn. Magn. Mater. 2006, 301 (1), 118–123.
29. Lugscheider, E., et al. Magnetron-sputtered Hard Material Coatings on Thermoplastic Polymers for Clean Room Applications. Surf. Coat. Technol. 1998, 108, 398–402.
30. Yahaya, M.Z., et al. Recent Characterisation of Sol-Gel Synthesised TiO2 Nanoparticles. Recent Appl. Sol–Gel Synthesis. 2017, 109.
31. Kammler, H.K.; Mädler, L.; Pratsinis, S.E. Flame Synthesis of Nanoparticles. Chem. Eng. Techno. Ind. Chem. Plant Equip. Process Eng. Biotechnol. 2001, 24 (6), 583–596.
32. D'Amato, R., et al. Synthesis of Ceramic Nanoparticles by Laser Pyrolysis: From Research to Applications. J. Anal. Appl. Pyrolysis 2013, 104, 461–469.
33. Cele, T. (2018). Synthesis of platinum group metals nanoparticles by gamma radiolysis (Doctoral dissertation).
34. Horikoshi S, Serpone N. Introduction to Nanoparticles, Microwaves in Nanoparticle Synthesis. 1st ed: Wiley-VCH Verlag GmbH & Co. KGaA; 2013
35. Riaz U, Ashraf SM, Madan A. Effect of microwave irradiation time and temperature on the spectroscopic and morphological properties of nanostructured poly(carbazole) synthesized within bentonite clay galleries. New Journal of Chemistry. 2014;38:4219-4228
36. Mohammadib M, Imanieha H, Ghammamya S. Rapid and efficient oxidation of organic compounds in microwave condition with new phase transfer oxidative agent: CTAMABC; 2008. DOI: 10.3390/ecsoc-12-01260
37. Marignier J, Belloni J, Delcourt M, Chevalier J. New microaggregates of non-noble metals and alloys prepared by radiation induced reduction. Nature. 1985;317:344-345
38. Abidi W, Remita H. Gold based nanoparticles generated by radiolytic and photolytic methods. Recent Patents on Engineering. 2010;4(3):170-188
39. Temgire MK, Bellare J, Joshi SS. Gamma radiolytic formation of alloyed Ag-Pt nanocolloids. Advances in Physical Chemistry. 2011; 9

40. Jayashree B, Ramnani SP, Tewari R. Short aspect ratio gold nanorods prepared using gamma radiation in the presence of cetyltrimethyl ammonium bromide (CTAB) as a directing agent. Radiation Physics and Chemistry. 2010;79(4):441-445
41. Gachard E, Remita H, Khatouri J, Keita B, Nadjo L, Belloni J. Radiation-induced and chemical formation of gold clusters. New Journal of Chemistry. 1998;22(11):1257-1265
42. Krklješ A. Radiolytic synthesis of nanocomposites based on noble metal nanoparticles and natural polymer, and their application as biomaterial (IAEA-RC--12071). International Atomic Energy Agency (IAEA); 2011
43. Chen Q, Shi J, Zhao R, Shen X. Radiolytic syntheses of nanoparticles and inorganic-polymer hybrid microgels (IAEA-RC--11242). International Atomic Energy Agency (IAEA); 2010
44. Hornebecq V, Antonietti M, Cardinal T, Treguer-Delapierre M. Stable silver nanoparticles immobilized in mesoporous silica. Chemistry of Materials. 2003;15(10):1993-1999
45. Shenava Aashritha Synthesis of silver nanoparticles by chemical reduction method and their antifungal activity. Int. Res. J. Pharm. 2013;4:111–113.
46. Lopez-Quintela M.A., Rivas J. Chemical reactions in microemulsions: a powerful method to obtain ultrafine particles. J. Colloid Interface Sci. 1993;158:446–451.
47. Li J, Wu Q, Wu J. Synthesis of nanoparticles via solvothermal and hydrothermal methods. Handbook of Nanoparticles; 2015, 1-28.
48. Sivasankaran S, Sankaranarayanan S, Ramakrishnan S. A novel sonochemical synthesis of metal oxides based Bhasmas. In: Materials Science Forum. Trans Tech Publications Ltd 2013;754:89-97.
49. Ziylan Yavas A, Mizukoshi Y, Maeda Y, Ince NH. Supporting of pristine TiO2 with noble metals to enhance the oxidation and mineralization of paracetamol by sonolysis and sonophotolysis. Appl Catal B 2015;172:7-17.
50. Das S, Srivasatava VC. Synthesis and characterization of ZnO–MgO nanocomposite by co-precipitation method. Smart Sci 2016;4:190-5.
51. Wang Y, Arandiyan H, Scott J, Bagheri A, Dai H, Amal R. Recent advances in ordered meso/macroporous metal oxides for heterogeneous catalysis: a review. J Materials Chem A 2017;5:8825-46.
52. Perez Tijerina E, Pinilla MG, Mejia Rosales S, Ortiz Mendez U, Torres A, Jose Yacaman M. Highly size-controlled synthesis of Au/Pd nanoparticles by inert-gas condensation. Faraday Discussions 2008;138:353-62.
53. Banerjee AN, Krishna R, Das B. Size controlled deposition of Cu and Si nano-clusters by an ultra-high vacuum sputtering gas aggregation technique. Appl Physics A 2008;90:299-303.
54. Meshesha BT, Barrabés N, Medina F, Sueiras JE. Polyol mediated synthesis and characterization of Cu nanoparticles: Effect of 1-hexadecylamine as stabilizing agent. In: Proceedings of the 1st WSEAS International Conference on Nanotechnology (Nanotechnology'09); 2009
55. Caroline Q, Bernard S, Miele P. Synthesis of praseodymium oxide nanoparticles. In: Nanomaterials and Nanotechnology. Vol. 4. No. Godište 2014; 2014. p. 1+
56. Feldmann C, Merikhi J. Synthesis and characterization of rod-like Y2O3 and Y2O3:Eu3+. Journal of Materials Science. 2003;38:1731-1735
57. Ragupathy P, Shivakumara S, Vasan HN, Munichandraiah N. Preparation of nanostrip V2O5 by the polyol method and its electrochemical characterization as cathode material for rechargeable lithium batteries. Journal of Physical Chemistry C. 2008;112:16700-16707
58. Sicard L, Le Meins JM, Méthivier C, Herbst F, Ammar S. Polyol synthesis and magnetic study of Mn3O4 nanocrystals of tunable size. Journal of Magnetism and Magnetic Materials. 2010;322:2634-2640
59. Lee S, Jeong S, Kim D, Hwang S, Jeon M, Moon J. ZnO nanoparticles with controlled shapes and sizes prepared using a simple polyol synthesis. Superlattices and Microstructures. 2008;43:330-339

60. Siemons M, Simon U. Gas sensing properties of volume-doped CoTiO3 synthesized via polyol method. Sensors and Actuators B: Chemical. 2007;126:595-603
61. Jiang XC, Wang YL, Herricks T, Xia YN. Ethylene glycol-mediated synthesis of metal oxide nanowires. Journal of Materials Chemistry. 2004;14:695-703
62. Flores-Gonzalez MA, Ledoux G, Roux S, Lebboua K, Perriat P, Tillement O. Preparing nanometer scaled Tb-doped Y2O3 luminescent powders by the polyol method. Journal of Solid State Chemistry. 2005;178:989-997
63. Jiang XC, Herricks T, Xia YN. Monodispersed spherical colloids of titania: Synthesis, characterization, and crystallization. Advanced Materials. 2003;15:1205-1209
64. Sun YG, Yin YD, Mayers BT, Herricks T, Xia YN. Uniform silver nanowires synthesis by reducing AgNO3 with ethylene glycol in the presence of seeds and poly(vinyl pyrrolidone). Chemistry of Materials. 2002;14:4736-4745
65. Bonet F, Grugeon S, Dupont L, Herrera Urbina R, Guery C, Tarascon J. Synthesis and characterization of bimetallic Ni–Cu particles. Journal of Solid State Chemistry. 2003;172:111
66. Tekaia-Elhsissen K, Bonet F, Silvert P-Y, Herrera-Urbina R. Finely divided platinum–gold alloy powders prepared in ethylene glycol. Journal of Alloys and Compounds. 1999;292(1-2):96-99
67. Garcia-Gutierrez D, Gutierrez-Wing CE, Giovanetti L, Ramallo-Lopez JM, Requejo FG, Jose-Yacaman M. Temperature effect on the synthesis of Au-Pt bimetallic nanoparticles. The Journal of Physical Chemistry B. 2005;109:3813-3821
68. Kim F, Connor S, Song H, Kuykendall T, Yang P. Platonic gold nanocrystals. Angewandte Chemie, International Edition. 2004;43(28):3673-3677
69. Wiley B, Sun Y, Mayers B, Xia Y. Shaped-controlled synthesis of metal nanostructure: The case of silver. Chemistry—A European Journal. 2005;11:454-463
70. Debnath, S., Swetha, D., & Babu, M. N. (2020). Green synthesis of nanoparticles using herbal extract. In Herbal Medicine in India (pp. 205-213). Springer, Singapore.
71. Lahiri, D., Nag, M., Sheikh, H. I., Sarkar, T., Edinur, H. A., Pati, S., & Ray, R. R. (2021). Microbiologically-synthesized nanoparticles and their role in silencing the biofilm signaling cascade. Frontiers in microbiology, 12, 636588.
72. Fariq, A., Khan, T., & Yasmin, A. (2017). Microbial synthesis of nanoparticles and their potential applications in biomedicine. Journal of Applied Biomedicine, 15(4), 241-248.
73. Jeevanandam, J., Chan, Y. S., and Danquah, M. K. (2016). Biosynthesis of metal and metal oxide nanoparticles. Chem. Bio. Eng. Rev. 3, 55–67.
74. Lovley, D. R., and Woodward, J. C. (1996). Mechanisms for chelator stimulation of microbial Fe(III)-oxide reduction. Chem. Geol. 132, 19–24. doi: 10.1016/S0009-2541(96)00037-X
75. Haefeli, C., Franklin, C., and Hardy, K. (1984). Plasmid-determined silver resistance in Pseudomonas stutzeri isolated from a silver mine. J. Bacteriol. 158, 389–392. doi: 10.1128/JB.158.1.389-392.1984
76. Iravani, S. (2014). Bacteria in nanoparticle synthesis: current status and future prospects. International scholarly research notices, 2014.
77. LewisOscar, F., Vismaya, S., Arunkumar, M., Thajuddin, N., Dhanasekaran, D., & Nithya, C. (2016). Algal nanoparticles: synthesis and biotechnological potentials. Algae-organisms for imminent biotechnology, 7, 157-182.