NANOPARTICLES: AN OVERVIEW ABOUT THEIR CLASIFICATIONS, SYNTHESIS, PROPERTIES, CHARACTERIZATION AND APPLICATIONS

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Abstract: Nanoparticles (NPs) are the main product of nanotechnologies. NPs are organic and inorganic structures, their size being less than one hundred nanometers. Due to their potential application in many fields metallic NPs are becoming increasingly important. There are numerous organisms possessing the ability to synthesise NPs and which therefore have the potential to be exploited and modified to optimise them to fulfil this purpose. Therefore, many bacteria, fungi and plants have shown the ability to synthesise metallic NPs but all have their own advantages and disadvantages. This "green" method of biological NPs production is a promising approach that allows synthesis in aqueous conditions, with low energy requirements and low-costs. The development of an environmentally friendly and inexpensive way of synthesising them is therefore crucial.

INTRODUCTION

Nanotechnology is an important field of modern research dealing with design, synthesis, and manipulation of particle structures ranging from approximately 1-100 nm. The word "nano" is derived from a Greek word meaning dwarf or extremely small. Nanobiotechnology involves research of technology in different fields of science like biotechnology, nanotechnology, physics, chemistry, and material science (Rai et al., 2008).

Nanotechnology involves intervention of novel strategies with the help of which atoms and small particles are manipulated. Progress in the field of nanotechnology has been rapid and with the development of innovative synthesis protocols and characterization techniques (Sharma et al., 2009). But most of the synthesis methods are limited to synthesis of nanoparticles (NPs) in small quantities and poor morphology (Sau and Rogach, 2010).

Chemical and physical synthesis methods often result in synthesis of a mixture of nanoparticles with poor morphology, and these methods also prove to be toxic to the environment due to the use of toxic chemicals and elevated temperatures for synthesis process (Birla et al., 2009).

The biosynthesis of NPs has been proposed as a cost-effective and as a rapid, eco-friendly alternative to chemical and physical methods. Metal nanoparticles produced using microorganisms and plant extracts are stable and can be monodispersed by controlling synthetic parameters, such as pH, temperature, incubation period, and mixing ratio. On the other hands, plant-mediated synthesis of NPs is a green chemistry approach that connects nanotechnology with plants. Among the biological alternatives, plants and plant extracts seem to be the best option because as it is known plants are nature's "chemical factories" (Parveen et al., 2016).

Recently, biological NPs were found to be more pharmacologically active than physico-chemically synthesized nanoparticles. Among the various biological NPs, those produced by medicinal plants have been found to be the most pharmacologically active, possibly due to the attachment of several pharmacologically active residues like secondary metabolites (Singh et al., 2016).

1. Classification of Nanoparticles

Nanoparticles can be classified based on the following criteria. From the point of view of origin, NPs can be natural and anthropogenic. On the other hands, they are broadly classified depending on the dimension:

● One dimensional system (thin film or manufactured surfaces) has been used for decades. Thin films (sizes 1–100 nm) or monolayer is now common places in the field of solar cells offering, different technological applications (chemical and biological sensors, optical device, fiber-optic systems);

● Two dimensions nanoparticles such as carbon nanotubes;

● Three dimensions nanoparticles such as Dendrimers, Quantum Dots, Fullerenes (Carbon 60), (QDs) (Hett, 2004).

Another classification of nanoparticles is depending on the chemical composition into the organic, inorganic and carbon based.

●*Organic nanoparticles*

Dendrimers, micelles, liposomes and ferritin, etc. are commonly knows the organic nanoparticles or polymers. These nanoparticles are biodegradable, non-toxic, and some particles such as micelles and liposomes have a hollow core (Table 1), also known as nanocapsules and are sensitive to thermal and electromagnetic radiation such as heat and light (Tiwari et al., 2008).

● *Inorganic nanoparticles*

Inorganic nanoparticles are particles that are not made up of carbon. Metal and metal oxide-based nanoparticles are generally categorised as inorganic nanoparticles.

◘ *Metal based*

These nanoparticles are synthesised from metals to nanometric sizes. Almost all the metals can be synthesised into their nanoparticles, but the commonly used metals are aluminium (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag) and zinc (Zn). On the other hands, the bimetallic list includes Fe–Co, Fe–Ni, Fe–Cu, Cu–Ni and Fe–Pt nanoparticles (Figure 1). The nanoparticles have distinctive properties such sizes as low as 10 to 100nm, surface characteristics like high surface area to volume ratio, pore size, surface charge and surface charge density, crystalline and amorphous structures, shapes like spherical and cylindrical and colour, reactivity and sensitivity to environmental factors such as air, moisture, heat and sunlight etc.

◘ *Metal oxides based*

The metal oxide-based nanoparticles are synthesised to modify the properties of their respective metal-based nanoparticles. Metal oxide nanoparticles are synthesised mainly due to their increased reactivity and efficiency (Tai et al., 2007). The commonly synthesised are Aluminium oxide (Al_2O_3), Cerium oxide (CeO_2), Iron oxide (Fe_2O_3), Magnetite (Fe_3O_4), Silicon dioxide (SiO2), Titanium oxide (TiO_2), Zinc oxide (ZnO). These nanoparticles have possessed exceptional properties when compared to their metal counterparts. Some of NPs have magnetic properties like Fe_3O_4, Co–Fe_2O_4 and Mn–Fe_2O_4 (McNamara and Tofail, 2017).

●*Carbon based*

The nanoparticles made completely of carbon are knows as carbon based (Bhaviripudi et al., 2007). They can be classified into fullerenes, graphene, carbon nano tubes (CNT), carbon nanofibers and carbon black and sometimes activated carbon in nano size (Figure 1).

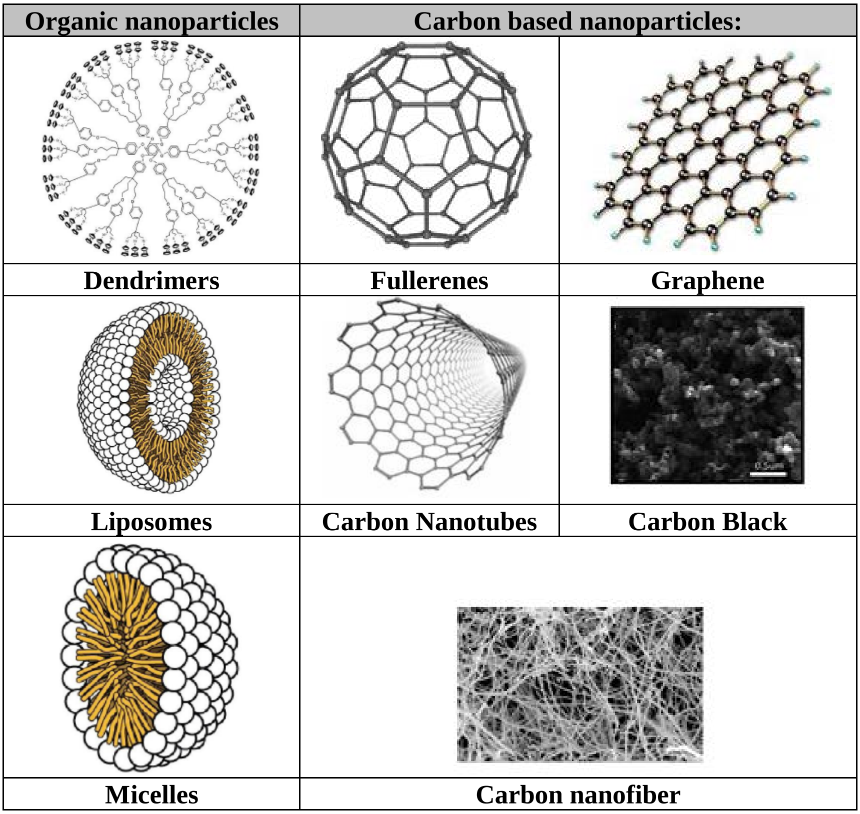

Figure 1. Organic nanoparticles (Dendrimers, Liposomes and Micelles) and Carbon-based nanoparticles (Fullerenes, Graphene, Carbon nanotubes, Carbon nanofibers and Carbon black) (Ealias and Saravanakumar, 2017)

2. Properties of Nanoparticles

The nanoparticles are of different shape, size and structure. It is spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc. or irregular and differs from 1 nm to 100 nm in size. The surface can be a uniform or irregular with surface variations. Some nanoparticles are crystalline or amorphous with single or multi crystal solids either loose or agglomerated (Machado et al., 2015). For characterization of nanoparticles there are necessary identifications of several parameters (Table 1).

The properties of nanoparticles are generally categorised into physical and chemical. The properties of few common nanoparticles are given in Table 2.

Table 1. Different parameters for characterization of nanoparticles (Wali et al., 2018)

Parameters	Instrument used
Particle size & size distribution	Zetasizer, Photon correlation spectroscopy, Mercury porosimetry, Laser diffractometry
Particle Morphology	Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), Atomic force microscopy (AFM)
Charge determination	Laser droplet anemometry, Zeta potentiometer
Metallic nature	X-ray diffraction (XRD) Analysis
Identification of Functional groups	Fourier Transform Infrared (FTIR) Spectroscopy
Chemical analysis of surface	Static secondary ion mass spectrometry
Release profile	In-vitro release characteristic under physiologic & sink condition

3. Methods of Nanoparticles Synthesis

The nanoparticles can be synthesized by various protocols using the *top-down* (physical) approach which deals with methods such as thermal decomposition, diffusion, irradiation, radiation, laser ablation, arc discharge, etc., and *bottom-up* (chemical and biological) approach which involves seeded growth method, polyol synthesis method, electrochemical synthesis, chemical reduction, condensation and biological entities for fabrication of nanoparticles Figure 2, Figure 3. Different synthesis methods involve the use of different types of chemical, physical, and biological agents to yield nanoparticles of different sizes and shapes.

Table 2. Physical and chemical properties of different nanoparticles (Ealias and Saravanakumar, 2017)

Nanoparticles	Properties
Carbon based nanoparticles	
Fullerenes	Safe and inert, semiconductor, conductor and superconductor, transmits light based on intensity
Graphene	Extreme strength, thermal, electrical conductivity, light absorption
Carbon Nano Tubes (CNT)	High electrical and thermal conductivity, tensile strength, flexible and elastic
Carbon Nanofiber	High thermal, electrical, frequency shielding, and mechanical properties
Carbon Black	High strength and electrical conductivity, surface area; resistant to UV degradation
Metal based nanoparticles	
Aluminium	High reactivity, sensitive to moisture, heat, and sunlight, large surface area
Iron	Reactive and unstable, sensitive to air (oxygen) and water
Silver	Absorbs and scatters light, stable, anti-bacterial, disinfectant
Gold	Interactive with visible light, reactive
Cobalt	Unstable, magnetic, toxic, absorbs microwaves, magnetic
Cadmium	Semiconductor of electricity, insoluble
Lead	High toxicity, reactive, highly stable
Copper	Ductile, very high thermal and electrical conductivity, highly flammable solids
Zinc	Antibacterial, anti-corrosive, antifungal, UV filtering

Bottom-up method

Bottom-up or constructive method is the build-up of material from atom to clusters to nanoparticles. Sol-gel, spinning, chemical vapour deposition (CVD), pyrolysis and biosynthesis are the most commonly used bottom-up methods for nanoparticle production (Table 3).

Top-down method

Top-down or destructive method is the reduction of a bulk material to nanometric scale particles. Mechanical milling, nanolithography, laser ablation, sputtering and thermal decomposition are some of the most widely used nanoparticle synthesis methods (Table 3).

3.1. Chemical synthesis of nanoparticles, the most often used method that use the chemical reduction method, which deals with the reduction of metal particles to nanoparticles using chemical reducing agents like sodium borohydride or sodium citrate (Cao and Hu, 2009).

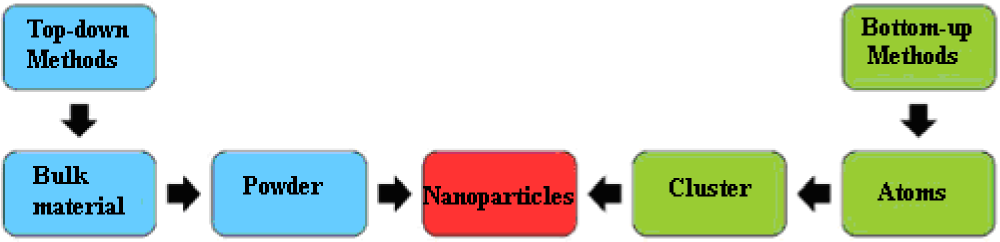

Figure 2. Nanoparticles synthesis process (Ealias and Saravanakumar, 2017)

3.2. Physical methods used for the synthesis of nanoparticles include thermal decomposition, laser irradiation, electrolysis, condensation, diffusion, etc. The thermal decomposition method is used for the synthesis of monodisperse nanoparticles. Fatty acids are dissolved in hot NaOH solution and mixed with metal salt solution which leads to formation of metal precipitate (Yang and Aoki, 2005).

3.3. Moreover, nanoparticles are synthesized through many physicochemical processes which have posed numerous pressures on the environment. Nowadays, eco-friendly attractive alternatives to chemical and physical methods are **biological synthesis** of nanoparticles synthesis using microorganisms (bacteria, yeast, fungi) and plants or plant extracts.

Thus, the *green synthesis* has been proposed as an alternative to reduce the use of hazardous compounds and harsh reaction conditions in the production of NPs. More than the biological approach is free of chemical toxins. Green synthesis of nanoparticles is a simple process, a metal salt is mixed with plant extract and the reaction completes in minutes to few hours at ordinary room temperature. Selection of solvent medium and selection of eco-friendly nontoxic reducing and stabilizing agents are the most important issues which must be considered in green synthesis of NPs. The metallic salt solutions are reduced into respective nanoparticles and for this reason have got considerable attention during the last decade because of simplicity (Wali et al., 2018).

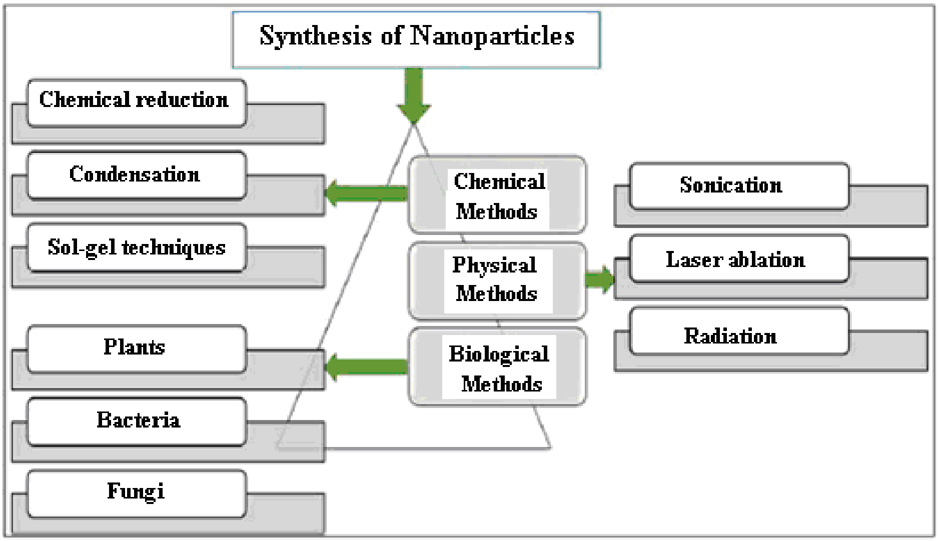

Figure 3. Various methods for making nanoparticles (Wali et al., 2018)

Biomolecules present in plant extracts can be used to reduce metal ions to nanoparticles in a single-step green synthesis process. Biogenic reduction of metal precursors to produce corresponding NPs is eco-friendly, less costly, free of chemical contaminants for medical and biological applications where purity of NPs is of major concern (Imtiyaz et al., 2016). Synthesis mediated by plant extracts is environmentally benign. The reducing agents involved include the various water-soluble plant metabolites (e.g. alkaloids, terpenoids, polyphenols, sugars, phenolic acids, and proteins) and co-enzymes (Mittal et al., 2013).

In addition, the biological method provides a wide range of resources for the synthesis of nanoparticles. The rate of reduction of metal ions using biological agents is found to be much faster at ambient temperature and pressure conditions. For instance, in case of synthesis of nanoparticles using *Aspergillus niger* synthesis of silver nanoparticles was observed within 2 h of treatment of fungal filtrate with silver salt solution (Gade et al., 2008).

On the other hand, the biological agents secrete a large number of enzymes, which are capable of hydrolyzing metals and thus bring about enzymatic reduction of metals ions (Rai et al., 2009). In case of fungi, the enzyme nitrate reductase is found to be responsible for the synthesis of nanoparticles (Kumar et al., 2007).

Table 3. Categories of the nanoparticles synthesised from the various methods (Ealias and Saravanakumar, 2017)

Category	**Method**	**Nanoparticles**
Bottom-up	Sol-gel	Carbon, metal and metal oxide based
	Spinning	Organic polymers
	Chemical Vapour Deposition (CVD)	Carbon and metal based
	Pyrolysis	Carbon and metal oxide based
	Biosynthesis	Organic polymers and metal based
Top-down	Mechanical milling	Metal, oxide and polymer based

	Nanolithography	Metal based
	Laser ablation	Carbon based and metal oxide based
	Sputtering	Metal based
	Thermal decomposition	Carbon and metal oxide based

The biggest advantage of biological synthesis based on fungal enzymes is the possibility of developing a rational approach for the biosynthesis of nanomaterials over a range of chemical compositions, which is currently not possible by other microbe-based methods.

Mechanism of biological nanoparticles biosynthesis

Biosynthesis of nanoparticles by microorganisms is an eco-friendly technology. Diverse microorganisms, both prokaryotes and eukaryotes are used for synthesis of metallic nanoparticles (silver, gold, platinum, zirconium, palladium, iron, cadmium and metal oxides such as titanium oxide, zinc oxide, etc). The synthesis of nanoparticles may be intracellular or extracellular according to the location of nanoparticles (Table 4).

Table 4. Synthesis of metallic nanoparticles by different microorganisms

Microorganism	**Type**	**Location**	**Size (nm)**
Phoma sp.	Ag	Extracellular	71.06–74.46
Fusarium oxysporum	Au	Extracellular	20–40
Verticillium sp.	Ag	Intracellular	25 ± 12
Trichoderma asperellum	Ag	Extracellular	13–18
Phaenerochaete chrysosporium	Ag	Extracellular	50–200

Intracellular synthesis of nanoparticles by fungi: This method involves transport of ions into microbial cells to form nanoparticles in the presence of enzymes. As compared to the size of extracellular reduced nanoparticles, the nanoparticles formed inside the organism are smaller. The size limit is probably related to the particles nucleating inside the organisms.

Extracellular synthesis of nanoparticles by fungi: Extracellular synthesis of nanoparticles has more applications as compared to intracellular synthesis since it is void of unnecessary adjoining cellular components from the cell. Fungi are mostly known to produce nanoparticles extracellularly because of their enormous secretory components, which are involved in the reduction and capping of nanoparticles (Narayanan and Sakthivel, 2010). Because of their tolerance and metal bioaccumulation ability, fungi have occupied the centre stage of studies on biological generation of metallic nanoparticles.

4. Characterization of Nanoparticles

Characterization of nanoparticles is based on the size, morphology and surface charge, using such advanced microscopic techniques. Properties like surface morphology, size and overall shape are determined by electron microscopy techniques. Features like physical stability and redispersibility of the polymer dispersion, as well as, their performance *in vivo* are affected by the surface charge of the NPs (Hett, 2004).

■ *Particle size*

Characterization of NPs is primarily evaluated by the particle size distribution and morphology, using electron microscopy. The images of Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM) are used for the measurement of particles and clusters whereas laser diffraction methods are used for measuring bulk samples in solid phase (Marsalek, 2014).

■ *Morphological characterizations*

The morphological features of NPs always attain great interest since morphology always influences most of the properties of the NPs. There are different characterization techniques for morphological studies, but microscopic techniques such as SEM and TEM are the most important.

■ *Surface morphology*

The NPs possess various shapes (include spherical, flat, cylindrical, tubular, conical and irregular shapes) and surface structures (like crystalline or amorphous) that play a key role in exploiting its properties. The surface is generally determined by electron microscopy imaging techniques like SEM and TEM (Hodoroaba et al., 2014).

■ *Surface Charge*

Surface charge and intensity determines the interaction of NPs with the biological environment as well as their electrostatic interaction with bioactive compounds. Generally, a zeta potentiometer is used for the measurement of surface charges and its dispersion stability in a solution. Zeta potential values can be utilized in evaluating surface hydrophobicity and the nature of material encapsulated within the nanocapsules or coated onto the surface (Pangi et al., 2003).

■ *Structural characterizations*

The structural characteristics are of the primary importance to study the composition and nature of bonding materials. It provides diverse information about the bulk properties of the subject material. The common techniques used to study structural properties of NPs are X-Ray Diffraction (XRD), energy dispersive X-ray (EDX), X-ray Photoelectron Spectroscopy (XPS), Infrared (IR) and Raman Spectroscopy.

■ *Composition*

The composition (chemical or elemental composition) measurement is usually carried out by X-ray photoelectron spectroscopy (XPS) (Sharma and Rao, 2014). Some techniques involve chemical digestion of the particles followed by wet chemical analysis such as mass spectrometry, atomic emission spectroscopy and ion chromatography. The particles in gaseous phase are collected either by filtration or electrostatically and spectrometric or wet chemical techniques are used for the analysis (Bzdek et al., 2011).

Once NPs are synthesized, it is important to fully characterize and understand their structure. Over the years, many methods and techniques have been developed for the analysis of various physicochemical properties of NPs. Different characterization techniques have been used for the analysis of various physicochemical properties of NPs.

Nanotechnology has massively grown up with the development of advanced electron microscopes and the main relevance techniques with will be presented below.

● **UV-visible absorption spectroscopy**: Absorbance spectroscopy is used to determine the optical properties of a solution. When the wavelength is varied and the absorbance is measured at each wavelength. The absorbance can be used to measure the concentration of a solution by using Beer-Lamberts Law.

● **X-ray diffraction (XRD) analysis**: X-ray diffraction is a conventional technique for determination of crystallographic structure and morphology. There is increase or decrease in intensity with the amount of constituent. This technique is used to establish the metallic nature of particles gives information on translational symmetry size and shape of the unit cell from peak positions and information on electron density inside the unit cell, namely where the atoms are located from peak intensities.

X ray diffraction analysis with various nanoparticles has been studied by various research workers to find the high crystallinity of the prepared sample.

● **Fourier Transform Infrared (FTIR)** spectroscopy measures infrared intensity vs. wavelength of light; it is used to determine the nature of associated functional groups and structural features of biological extracts with nanoparticles. The calculated spectra clearly reflect the well-known dependence of nanoparticle optical properties.

● **Photon-Correlation Spectroscopy (PCS) or Dynamic Light Scattering (DLS)** Current research demands the fastest and most popular method of determining particle size. The fastest and most popular techniques like photon-correlation spectroscopy (PCS) or dynamic light scattering (DLS), widely used to determine the size of Brownian nanoparticles in colloidal suspensions in the nano and submicron ranges. In this technique solution of spherical particles in Brownian motion causes a Doppler shift when they are exposed against shining monochromatic light (laser).

● **Scanning Electron Microscopy (SEM)**

This electron microscopy-based technique determines the size, shape and surface morphology with direct visualization of the NPs. Therefore scanning electron microscopy offer several advantages in morphological and sizing analysis.

During the process of SEM characterization, solution of nanoparticles should be initially converted into a dry powder. This dry powder is then further mounted on a sample holder followed by coating with a conductive metal (e.g. gold) using a sputter coater. Whole sample is then analyzed by scanning with a focused fine beam of electrons (Jores et al., 2004). Secondary electrons emitted from the sample surface determine the surface characteristics of the sample. This electron beam can often damage the polymer of the nanoparticles which must be able to withstand vacuum.

● **Transmission Electron Microscope (TEM)**

Experimental difficulties in studying nanostructures stem from their small size, which limits the use of traditional techniques for measuring their physical properties. TEM techniques can provide imaging, diffraction and spectroscopic information, either simultaneously or in a serial manner, of the specimen with an atomic or a sub-nanometer spatial resolution. TEM operates on different principle than SEM, yet it often brings same type of data.

The sample preparation for TEM is complex and time consuming because of its requirement to be ultrathin for the electron transmittance. High-resolution TEM imaging, when combined with nanodiffraction, atomic resolution electron energy-loss spectroscopy and nanometer resolution X-ray energy dispersive spectroscopy techniques, is critical to the fundamental studies of importance to nanoscience and nanotechnology.

5. Exemples of Metallic Nanoparticles

5.1. Silver nanoparticles (AgNPs) have unique physicochemical properties such as high electrical conductivity and thermal conductivity, chemical stability, catalytic activity, enhanced optical properties and antimicrobial efficacy against bacteria, viruses as well as other eukaryotic micro-organisms (Gong et al., 2007, McNamara and Tofail, 2017). Because of AgNPs extraordinary antimicrobial activity it is mainly used in the medical industry for textiles, wound dressings and device coatings. However, AgNPs are used in biomedical applications such as biosensors and photothermal therapy and drug delivery.

AgNPs have toxic properties that can inhibit bacterial growth, are hazardous to zebrafish and the human reproductive system, and are lethal to cell-based *in vitro* systems; they are still abundantly utilized in several commercial products such as contraceptive devices and feminine hygiene products. There are potential environmental and health alerts since the toxicity threat of AgNPs can be observed near the vicinity of consumers, particularly in the freshwater ecosystem (Syafiuddin et al., 2017). AgNPs can be synthesized by several approaches including physical, chemical, and biological (Figure 4). In general, equipment constraints, cost, and time consumption are identified as the major factors influencing the method of synthesis.

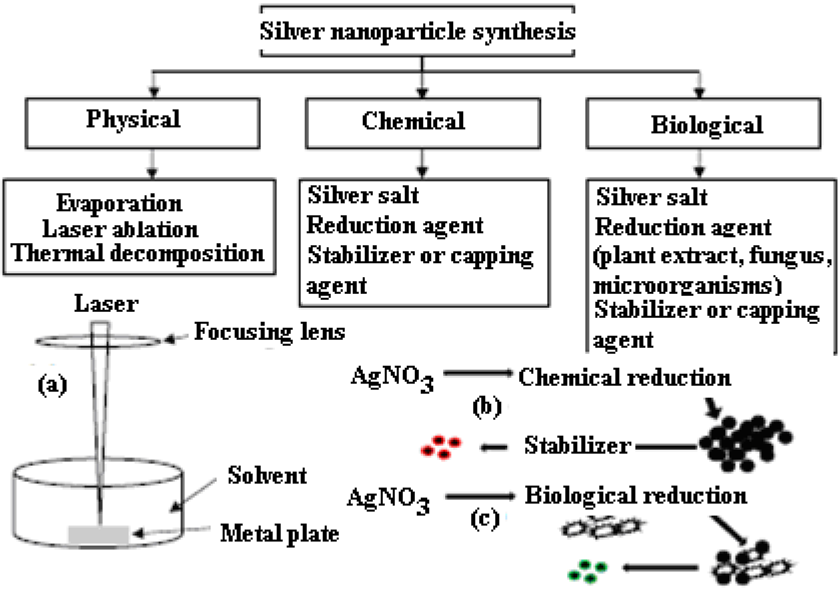

Figure 4. General procedures to synthesize silver nanoparticles by different approaches (Syafiuddin et al., 2017).

● Generally, the *physical approach* used to synthesize AgNPs employs the evaporation-condensation method. A new method was proposed by Tsuji et al., 2006 for synthesizing AgNPs by a laser ablation technique. Employing an alternative approach, AgNPs were synthesized using thermal decomposition by Lee and Kang, 2004.

●*The chemical approach* is widely used for synthesizing AgNPs using water or organic solvents. It is an easy way to synthesize AgNPs in solution (Quang Huy et al., 2013). A chemical reduction method was adopted for synthesizing AgNPs of various sizes using gallic acid (Martínez-Castañón et al., 2008). In addition, AgNPs were successfully synthesized from a silver ammonia solution (Tollens' reagent, 0.1 mol/L) where particles with sizes from 10 to 30 nm were observed on the surface of bacterial cellulose nanofibers (Wu et al., 2014). $AgNO_3$ as silver salt, aniline as reducing agent, and cetyltrimethylammonium bromide as stabilizer were also used to synthesize AgNPs (Khan et al., 2011). In case of AgNPs chemical synthesis, three main components are needed: a silver salt (usually $AgNO_3$), a reducing agent (i.e. ethylene glycol) and a stabilizer or capping agent (i.e. PVP) to control the growth of the NPs and prevent the aggregating.

● Recently, the *biological approach* for synthesizing AgNPs is being increasingly considered. This method is a green technology aimed at minimizing the negative environmental impact. The reducing agent and the stabilizer for AgNPs biological synthesis are replaced by molecules produced by living organisms such as plants, bacteria, fungi, yeast, and algae.

Thus, nowadays, a simple and eco-friendly green approach for synthesis of AgNPs by various plant extracts have drawn the attention of researchers because of its advantage over physical and chemical methods. Synthesis of NPs by green approach is emerging field because of its various advantages over the other process like nontoxic, ecofriendly and low cost (Kumar et al., 2017). Studies have already reported the successful biosynthesis of AgNPs by plants such as *Azadirachta indica, Cinnamomum camphora, Glycine max, Jatropha curcas, Cinnamomum camphora, Phyllanthus amarus, Carica papaya, Gliricidia sepium, Coriandrum sativum* (Deepak et al., 2011).

5.2. Gold nanoparticles (AuNPs)

The importance of AuNPs was recognized over 150 year back when Michael Faraday observed different properties of colloidal gold solution differing from their bulk material, gold. AuNPs are important components for biomedical applications. More precisely, AuNPs have been widely employed for diagnostics, and have seen increasing use in the area of therapeutics (Yeh et al., 2012). In recent times, biosynthesis and applications of AuNPs has been highly acknowledged.

The usual synthetic route to prepare gold nanoparticles involves the reduction of a gold salt (usually a halide, $HAuCl_4x3H_2O$) in solution by various reducing agents in the presence of a stabilizer (sodium citrate) (Andries et al., 2016, Lengke et al., 2011). The use of rapid reductants (e.g., white phosphorus, tannic acid, formamide, o-anisidine) results in bigger and generally spherical nanoparticles, while weak reducing agents (e.g., citrate, tartarate).

AuNPs are used in immunochemical studies for identification of protein interactions. They are used as lab tracer in DNA fingerprinting to detect presence of DNA in a sample. They are also used for detection of aminoglycoside antibiotics like streptomycin, gentamycin and neomycin. Gold nanorods are being used to detect cancer stem cells, beneficial for cancer diagnosis and for identification of different classes of bacteria.

5.3. Alloy nanoparticles exhibit structural properties that are different from their bulk samples (Ceylan et al., 2006). Since Ag has the highest electrical conductivity among metal fillers and, unlike many other metals, their oxides have relatively better conductivity, Ag flakes are most widely used. Bimetallic alloy nanoparticles properties are influenced by both metals and show more advantages over ordinary metallic NPs.

5.4. Cooper nanoparticles is reported effective against spread by *Xanthomonas* sp. such as rise bacterial blight disease (*Xanthomonas oryzae*) and leaf spot of mung by *Xanthomonas campestris.* Esteban-Tejeda et al., (2009) reported that Cu nanoparticles have broad spectrum antimicrobial activity against Gram positive and negative bacteria and fungi at low concentration it can be used as a fungicide.

5.5. Silica nanoparticles

Silica is recognized as a vital element in plant physiological activities and growth inducer (Kanto et al., 2006) which would helpful in proliferation of stress resistance capability of diseased plants. Silica nanoparticle in combination with Ag (Ag-Si) nanoparticle showed anti-bacterial and anti-fungal activity (Park et al., 2013). Barik et al., 2008, used nano-silica as a pesticide against insect and reported that nano-silica absorbed into the cuticule lipid of insect by physio-sorption and kill insects.

5.6. Zinc nanoparticles has been used as nonfertilizer on many crops and its showed positive results in oprimal concentration, but the ZnO as fungicidal against fungal plant pathogen is less studied.

5.7. Selenium nanoparticles

Selenium (Se) is an essential micronutrient for humans, animals, and other organisms (El-Ramady et al., 2014). However, in higher plants, the role of selenium nanoparticles (SeNPs) has not been demonstrated clearly. Earlier studies have indicated that soil and/or foliar application of Selenium improved the antioxidant capacity in basil (*Ocimum basilicum* L.), (Oraghi Ardebili et al., 2015, Oprica et al., 2018) growth in tobacco (*Nicotiana tabacum* L.), (Jiang, et al., 2015) and yield in mustard (*Brassica rapa* L.) (Lyons et al., 2014), in potato (*Solanum tuberosum* L.) (Turakainen et al., 2004). Decreased lipid peroxidation and cell membrane damage through increased superoxide dismutase (SOD) and glutathione peroxidase (GPX) enzymes activity by Se application explains its antioxidative activity (Djanaguiraman et al., 2005).

Elemental Se is not soluble in water and biologically inert because of its redox state. However, nanosized elemental Se-NPs were found to possess prominent bioactivity and biosafety properties (Wang et al., 2007, Zhang, et al., 2008). Studies have shown that the biological activity and antioxidant property of SeNPs increase with their surface-to-volume ratio and decreasing particle size (Zhang et al., 2001).

Selenium nanoparticles (SeNPs) represent what it believes to be a novel prospect for nutritional supplementation because of their lower toxicity and ability to gradually release selenium after ingestion. SeNPs demonstrate anticancer and antimicrobial properties that may contribute to human health, not only as dietary supplements, but also as therapeutic agents (Skalickova et al, 2017).

6. Nanoparticles applications

Having significant applications, nanoparticles are used or being evaluated for use, in many fields like biomedical, food industry, agriculture.

6.1. Applications of nanoparticles in cosmetics and sunscreens

The conventional ultraviolet (UV) protection sunscreen lacks long-term stability during usage. Thus, the UV protection property of titanium oxide and zinc oxide nanoparticles as they are transparent to visible light as well as absorb and reflect UV rays found their way to be used in some sunscreens. Moreover, some lipsticks use iron oxide nanoparticles as a pigment (Wiechers and Musee, 2010).

6.2. Biomedical applications of nanoparticles

Nanotechnology provides us with the opportunity of achieving smart nanostructures with complex functionalities including local heating, targeting (passive or active), improved uptake, delivery, biocompatibility, suitable biodistribution, or no immunogenicity, to name a few.

More than nanoparticle can be used in cancer treatment. There are a variety of nanoparticle systems currently investigated and explored for biomedical applications with some particular emphasis for cancer therapeutics; hence some precious metals (mainly gold and silver systems, Au, and Ag) and some magnetic oxides (in particular magnetite Fe_3O_4) received much interest including quantum dots and some of what is called natural nanoparticles (Bououdina et al., 2013).

The use of local heating by bioactive NPs can drastically reduce the side effects (cell toxicity and/or tissue radiation damage) of traditional treatments when used in combined therapies. There is also another approach to destroy tumors by NP-based heating, that is, increasing the temperature above 46^0C and, therefore, causing cell death by necrosis; in contrast to apoptosis (the other known cellular death), necrosis occurs when cells suffer an irreversible damage (Pablo del Pino and Pelaz, 2012). Hyperthermia is different from “ablative” techniques, which use heat from ultrasound waves, radio waves or lasers, to destroy cancer cells. “In those treatments, the heat itself is high enough to ‘cook’ the cancer”. In mild temperature hyperthermia, it is use lower temperatures (1090 to 110˚ F) to allow radiation therapy or chemotherapy to work better and this often shrinks the tumour.

Nanotechnology has improved the medical field by use of nanoparticles in drug delivery. NPs have been produced to deliver drugs, proteins/peptides and genes, to be used in various biomedical areas including cancer therapy and vaccination (Ashaben et al., 2014). In fact, NPs can be used in various administration routes, such as oral, nasal, parenteral or intraocular, representing and efficient and effective improvement over current methods. The drug can be delivered to specific cells using nanoparticles (Ganesh and Archana, 2013). The total drug consumption and side effects are significantly lowered by placing the drug in the required area in required dosage. This method reduces the cost and side effects (Mudshinge et al., 2011).

6.4. Applications of nanoparticles in food

Nanofood is a term used to describe foods that use nanotechnology techniques, tools or manufactured nanomaterials that have been added during cultivation, production, processing or packaging. For example, a nanocomposite coating in a food packaging process can directly introduce the anti-microbial substances on the coated film surface (Laad and Jatti, 2016). One of the examples is the canola oil production industry includes nanodrops, an additive designed to transfer the vitamins and minerals in the food. There are several purposes for the development of nanofood like improvement of food safety, enhancement of nutrition and flavor, and cutting production and consumer costs. On the other hand, nanofood provides various benefits by which include health promoting additives, longer shelf lives and new flavour varieties.

The application of nanotechnology in food is rapidly emerging and is involving all areas of the food chain from agricultural applications to food processing and enhancing bioavailability of nutrients (Heera and Shanmugam, 2015).

6.5. Applications of nanoparticles in agriculture

6.5.1. Nanoparticles as insecticides

Synthetic agrochemicals have changed the face of agriculture, but it has also developed new challenge in form of insect pest resistance. Applications of different type of nanoparticles (silver nanoparticles, aluminium oxide, zinc oxide and titanium dioxide) in the control of rice weevil (caused by *Sitophilus oryzae*) and grasserie disease in silkworm (caused by *Bombyx mori* and baculovirus BmNPV (*B. mori* nuclear polyhedrosis virus) were studied (Goswami et al., 2010).

The entomotoxicity of silica nanoparticles against rice weevil *Sitophilus oryzae* was tested by Debnath et al. 2011, which compared the efficacy with bulk-sized silica (individual particles larger than 1.0 µm). Amorphous silica nanoparticles were found to be highly effective against this insect pest causing more than 90% mortality, indicated the effectiveness of silica nanoparticles to control insect pests. Moreover, Teodoro et al., 2010 reported that insecticidal activity of nanostructured alumina against *Sitophilus oryzae* L. and *Rhyzopertha dominica* evidenced significant mortality after 3 days of continuous exposure to nanostructured alumina-treated wheat.

6.5.2. Nanoparticles as fungicides.

Fungal diseases among crops cause major loss to the production. Nanoparticles have been experimented as antifungal agents against pathogenic fungi and their application have not causes effects to plants. Shyla et al., 2014, has been tested the antifungal activity of nanoparticles of zinc oxide (35–45 nm), silver (20–80 nm) and titanium dioxide (85–100 nm) against *Macrophomina phaseolina*. The higher antifungal effect was observed in silver nanoparticles at lower concentrations than zinc oxide and titanium dioxide nanoparticles.

6.5.3. Nanoparticles as micronutrient supply

It is known that micronutrients like manganese, copper, boron, iron, molybdenum, zinc etc. are important for the growth and development. Foliar application of micronutrients can enhance uptake by the leaves (Martens and Westermann, 1991). Nanotechnology can be used to make the availability of micronutrients to plants. Nano formulations of micronutrients can be sprayed on plants or can be supplied to soil for uptake by roots to enhance soil health and vigor (Peteu et al., 2010). Different nanoparticles have been tested to provide appropriate level of micronutrients in plants.

Foliar application of iron compounds by the nanoparticle's technology may be a solution to plants growing in iron deficiency soils with high pH and calcareous. Thus, Ghafariyan et al., 2013 showed that iron oxide nanoparticles could be used as a source of iron for soybean for reducing chlorotic symptoms of iron deficiency.

In addition, application of iron nanoparticles also improved crop black-eyed peas performance more than that by application of a regular iron salt (Delfani et al., 2014). On the other hand, manganese nanoparticles have been reported to enhance growth of mung bean (*Vigna radiata*) and photosynthesis (Pradhan et al., 2013).

6.5.4. Nanoherbicides

Nanoherbicides can play a very important role in removing weeds from crops in an eco-friendly way, without leaving any harmful residues in soil and environment (Pérez-de-Luque and Rubiales, 2009)

The resistance of weeds against herbicides appears by continuous use of same herbicide for constant period of time cause. Encapsulation of herbicide in polymeric nanoparticles also results in environmental safety (Kumar et al., 2015). These molecules enter into the roots system of the weeds, translocate to cells and inhibit metabolic pathways such as glycolysis. This ultimately leads to death of plants (Ali et al., 2014).

CONCLUSIONS

Nanotechnology is improving our everyday lives by enhancing the performance and efficiency of everyday objects.
Having significant applications, nanoparticles are used or being evaluated for use, in many fields like biomedical, food industry, agriculture. In the biomedical field, these nanoparticles have been investigated for antimicrobial applications, biosensing, imaging, and drug delivery. In the environmental field, nanoparticles have been investigated for applications in bioremediation of diverse contaminants, water treatment, and production of clean energy. The nanotechnology has a great future due to its efficiency and environmental friendly property.

It provides a clean environment by providing safer air and water, and clean renewable energy for a sustainable future. Nanotechnology has established to be an advanced field of science where extensive research is carried out to implement the technology. It is being tested for various new applications to increase the efficiency and performance of the object or process and subsequently reduce the cost so that it is accessible for everyone. The nanotechnology has a great future due to its efficiency and environmental friendly property.

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