Synthesis, Characterization, and Application of Biogenic Nanomaterials: An Overview

Shruti Kakkar, Bhupendra Harjani, Naresh Ledwani and Lalita Ledwani

Abstract Nanotechnology is the most promising and interdisciplinary field of research that has been growing rapidly worldwide in different fields. Nanotechnology commits a sustainable development through its continuous growth toward green chemistry to develop "green nanotechnology". Green nanotechnology is implementation of green chemistry and green engineering principles in the field of nanotechnology to influence the size of nanoparticles within a nanoscale range to make biogenic nanoparticles. These biogenic nanomaterials can help in solving serious environmental challenges in the area of wastewater treatment, pollutant removal, fatal diseases, climate change, and solar energy conversion. This review provides a brief idea about the current potential applications of nanotechnology into the bio-environmental systems and how this technology can help in the synthesis of biogenic nanoparticle. Biogenic synthesis of nanoparticles is an environmentally friendly approach; it reduces environmental pollutants and conserves natural resources without creating any environmental damages.

Keywords Nanotechnology · Green nanotechnology · Nanomaterials · Biogenic · Bio-environment

S. Kakkar · L. Ledwani (✉)
Department of Chemistry, Manipal University Jaipur, Rajasthan, India
e-mail: lalita.ledwani@jaipur.manipal.edu

B. Harjani
F H Medical College, Etmadpur, UP, India

N. Ledwani
Bhagwan Mahaveer Cancer Hospital and Research Centre, Jaipur, Rajasthan, India

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1 Introduction

1.1 Nanotechnology

Nanotechnology has recently become the most important area of research which deals with the manufacturing of new materials; it creates new processes and new applications (Ibrahim et al. 2016). Nanoparticles are synthesized by numerous physical, chemical, and biological methods. A biological method includes microbes, fishes, plants, and so on, for manufacturing of biogenic nanoparticles. This biological process does not involve any harmful chemicals and solvent. This method of nanoparticle synthesis is termed as "green synthesis".

It combines knowledge from diverse dimensions of science and found a major contribution to the field of physics, chemistry, biology, and medicine. It is one of the most rapidly growing fields of technology that has raised variety of new frontiers of research. Recently, nanotechnology focused on developing "clean" and "green" technologies which have various significant environmental benefits and has become a brand known as "green technology".

Nanotechnology is also formed in conjugation with biotechnology and engineering technologies, for synthesis of environment-friendly biogenic nanoparticles. The nanoparticles made from green innovations are eco-friendly, energy-efficient, reduce waste, and diminish greenhouse gas emissions. These nanoparticles have several advantages because of uniform size and shape. They remove harmful chemicals and pollutants from environment by counteracting them or through alteration in various synthesis conditions. These synthesized nanoparticles do not disturb earth's ecosystem and also conserves its natural resources (Ali Mansoori et al. 2008; Bhavani et al. 2014).

1.2 Green Technology and Green Nanotechnology

Green technology is an environment-friendly and innovative technology which conserves natural resources in order to make a sustainable development. The major goals of this technology are to reduce non-renewable resource, reduce energy usage, and increase the human quality in life without damaging natural resources on earth. This includes environment sustainability, source reduction, energy, green building, and green chemistry.

Green nanotechnology is the branch of green technology, with green energy system, green information technology, that uses green chemistry and green engineering principles. The principles of this technology are to produce safer and sustainable nanoparticles. For sustainable development of these nanoparticles, the biogenic process is required nowadays because they are eco-friendly, cost-effective, and consume less energy; it does not impart any hazardous effect on the environment and produces safer products and by-products (Patra and Baek 2014; Rani and Sridevi 2017).

2 Approaches for the Synthesis of Nanoparticles

Nanoparticles (NPs) are a group of substances where at least one dimension is lesser than the 100 nm. A nanoparticle shows various properties, such as enhanced reactivity, sensitivity, surface area, and stability. Nanoparticles are mainly divided into two parts: organic and inorganic nanoparticles. Natural or organic nanoparticles include carbon nanoparticles such as fullerenes, and inorganic nanoparticles include magnetic nanoparticles, steel nanoparticles (like silver and gold), and semiconductor nanoparticles (like titanium dioxide, magnesium, and zinc oxide). Various methods are used to increase the properties of nanoparticles and reduce the production costs. The processing conditions of nanoparticles are needed to be controlled for identical shape, identical size, and identical chemical composition of the particles (Ali Mansoori et al. 2008).

According to Siegel, nanomaterials are differentiated by 0-dimensional, 1-dimensional, 2-dimensional, and 3-dimensional (Lusvardi et al. 2017). The nanomaterials exist in different forms, such as single, fused, and aggregated with spherical, tubular, and irregular shapes. Nanoparticles are synthesized by two approaches: top-down and bottom-up (Mom et al. 2007).

The top-down approach includes the breaking of larger materials into smaller nanoparticles. It refers to slicing and breaking of large material to get nano-sized particles. And the bottom-up approach or constructive method refers to building up of the material from the bottom: atom by atom, molecule by molecule, which means a build-up of material from atom to clusters to nanoparticles (Chen et al. 2014; Marchiol 2012; Shukla et al. 2017). Top-down approach is mainly used in microfabrication methods. Attrition and milling for making nanoparticles are examples of top-down processes. The bottom-up approach is mainly used in the concept of molecular self-assembly. Synthesis of biogenic nanoparticles with the help of microorganism and plants by bottom-up approach is a very prominent, easy, and cost-effective method to synthesize green nanoparticles. The synthesis of nanoparticles by top-down and bottom-up approaches is shown in Fig. 1.

2.1 Synthesis of Nanoparticles

Various conventional techniques and several methods are used for manufacturing of nanoparticles (NPs). A couple of processes like physical, chemical, and biological are used for the synthesis of nanoparticle. Physical methods include plasma arcing, ball milling, thermal evaporate, pyrolysis, laser deposition, and so on. The chemical methods include colloids, colloids solution, and sol–gel method for nanoparticles synthesis. But these methods are costly and affect human health by causing certain environmental risks on the atmosphere and the survival of all organisms. The non-toxic and eco-friendly methods for manufacturing of nanoparticles are biological methods. The biogenic synthesis of nanoparticles with exact dimension and shapes

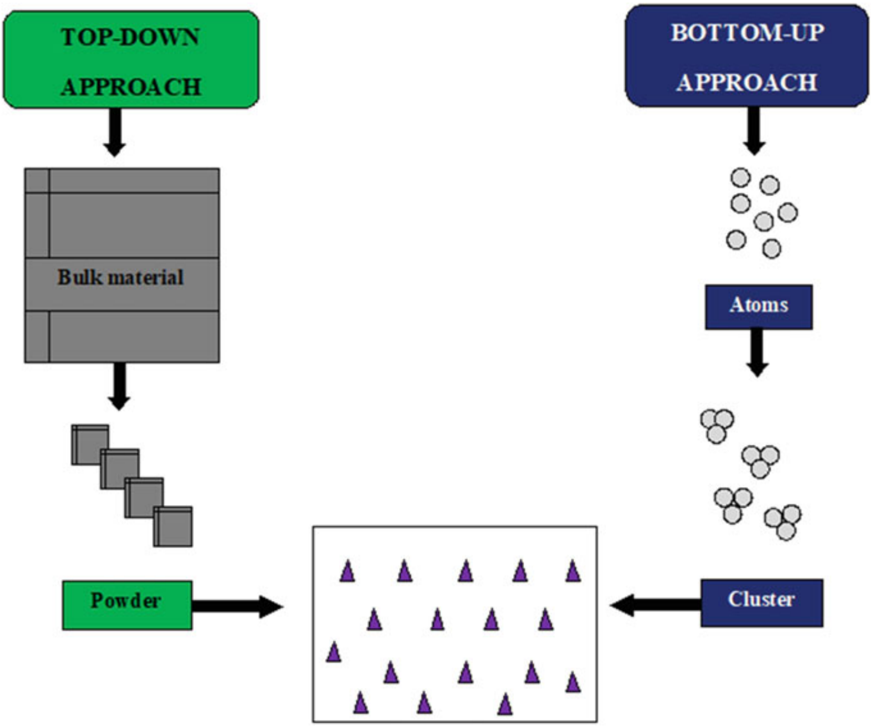

Fig. 1 Approaches for the synthesis of nanoparticles

is considered as cost-effective and novel method in biomaterial science. The synthesis of nanoparticles from biogenic methods is now most commonly used for medical, agriculture, and environmental purposes. A symmetric representation of different methods used for the manufacturing of these nanoparticles is shown in Fig. 2.

Biogenic synthesis includes the use of naturally present microorganism for the synthesis of nanoparticles. Microorganisms and pathogen cells are interacting with metals and form nanoparticles. The most commonly used microorganisms are fungi bacteria and algae. Except bacteria and fungi, on the other hand, plants are also used for the synthesis of nanoparticles in the past few years. Several parts of plants have also been used for the synthesis of nanoparticles, such as leaves, stems, shoots roots, flowers, and barks. In the biological method, the yield of nanoparticles is very high as compared to other conventional methods of synthesis and they do not cause any environmental problems. These biogenic nanoparticles are non-toxic in nature, biodegradable, and environment-friendly. The synthesis of biogenic nanoparticles is shown in Fig. 3.

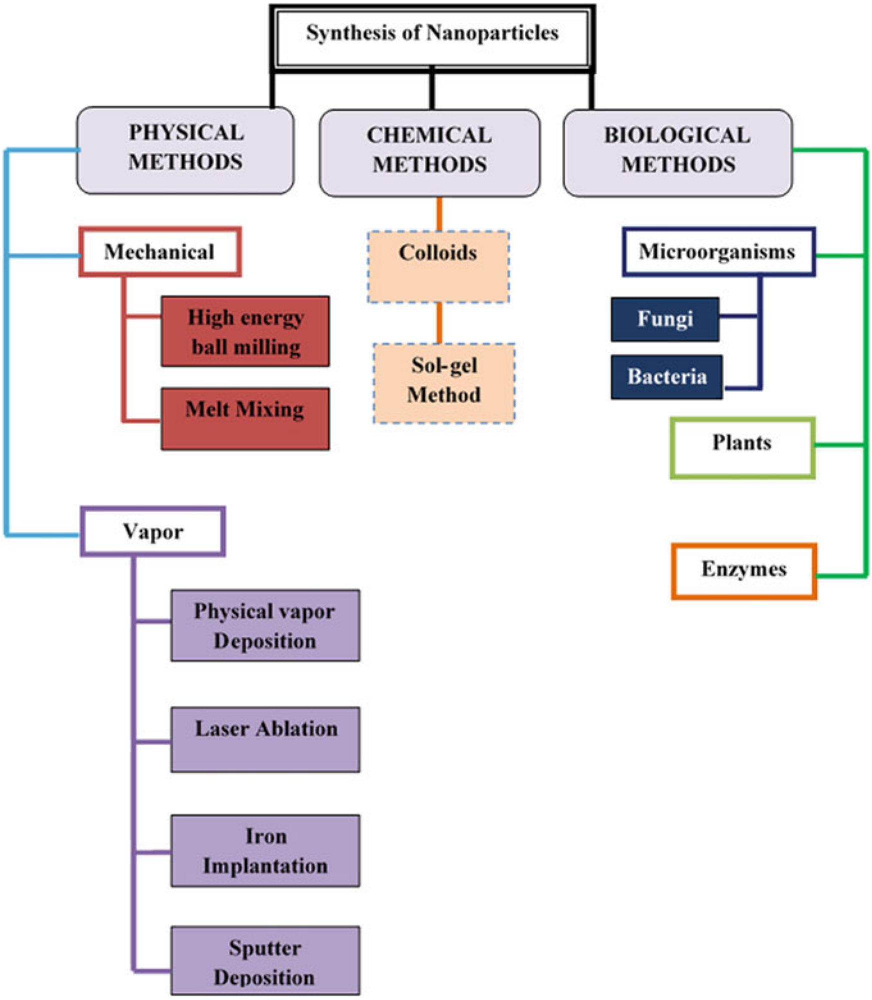

Fig. 2 Methods for the synthesis of nanoparticles

2.2 *Types of Nanoparticles*

2.2.1 Metal Nanoparticles

Metal nanoparticles are a type of nanoparticle mainly synthesized by biological methods. They help to protect the system against toxic effects of metal ion concentration. Different microorganisms and plants show tolerance to metal ions through this system. The most commonly used microorganism for the synthesis of metal nanoparticles is bacteria and fungi. The mainly synthesized metal nanoparticles through biological system are silver and gold nanoparticles.

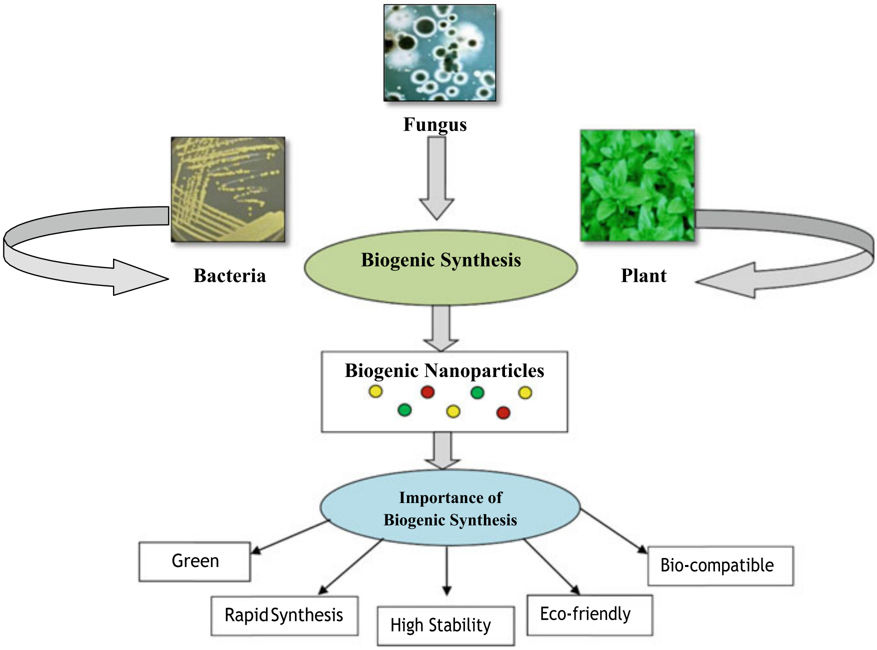

Fig. 3 Biogenic synthesis of nanoparticles

(a) **Silver nanoparticles (Ag-NPs)**

Silver is one of the fundamental elements that make up our planet (Mom et al. 2007). Conventionally, the silver NPs are synthesized by various chemical methods. Silver NPs are ultrafine particles of silver. They are 10–100 nm large and differ from the bulk silver as they have different color, such as yellow, as opposed to the silver (Carlson et al. 2008; Chaloupka et al. 2010; Morones et al. 2005). The two most conventional methods for synthesizing silver nanoparticles (Ag-NPs) via chemical reduction are Turkevich method (1951), where silver is reduced by trisodium citrate, and Brust method (1994), where silver is reduced by sodium borohydride. For biomedical applications, mainly bacteria, fungi, and plants are used. They produce very large amount of silver nanoparticles which show high antibacterial and antimicrobial activities against known pathogens.

The most commonly used biochemical methods for production of silver NPs are silver nitrate and plant extracts. In the biochemical reactions, $AgNO_3$ reacts with plant extracts and form Ag-NPs. There are several advantages of biogenic synthesis over the chemical synthesis of silver nanoparticles: the low cost, eco-friendly nature, and antimicrobial properties of silver show considerable attention in bio-environment system (Chen and Schluesener 2008). Because of higher antimicrobial properties the silver nanoparticles are widely used in various pharmaceuticals and biomedical treatments (Chugh et al. 2018; Natsuki et al. 2015; Sotiriou and Pratsinis 2011).

Nowadays, silver NPs also show a wide range of applications in wastewater treatments, laundry detergents, and other cleaning stuffs (He et al. 2018; Rai et al. 2012). Various properties of silver and silver nanoparticles are shown in Fig. 4.

(b) **Gold nanoparticles (Au-NPs)**

Gold nanoparticles (Au-NPs) are most commonly used in biotechnology and biomedical areas because of their large surface area and high electron conductivity. Gold nanoparticle is used as in assemblies of oligonucleotides, antibodies, and proteins to form bioconjugates. These bioconjugates show various applications in biomedical and biomaterials fields (Katas et al. 2018; Kefayat et al. 2019; Khan and Rizvi 2014; Khan et al. 2014; Lee et al. 2007; Vu et al. 2019). Au-NPs are emerging as a promising agent for cancer therapy and also proved to be the safest and much less toxic agents for drug delivery. Gold nanoparticles occur as a cluster of gold atoms up to 100 nm in diameter. The conventional methods for synthesizing gold nanoparticles (Au-NPs) via chemical reduction are the Turkevich method, Brust method, and Martin method. The biogenic synthesis of gold nanoparticles is also done by various microorganisms like bacteria and fungi. For the synthesis of biogenic gold NPs, the most commonly used microorganisms are *Pseudomonas aeruginosa* and *Rhodopseudomonas* (Singh et al. 2014, 2015). Schematic representations of gold nanoparticles used in biomedical practices are shown in Fig. 5.

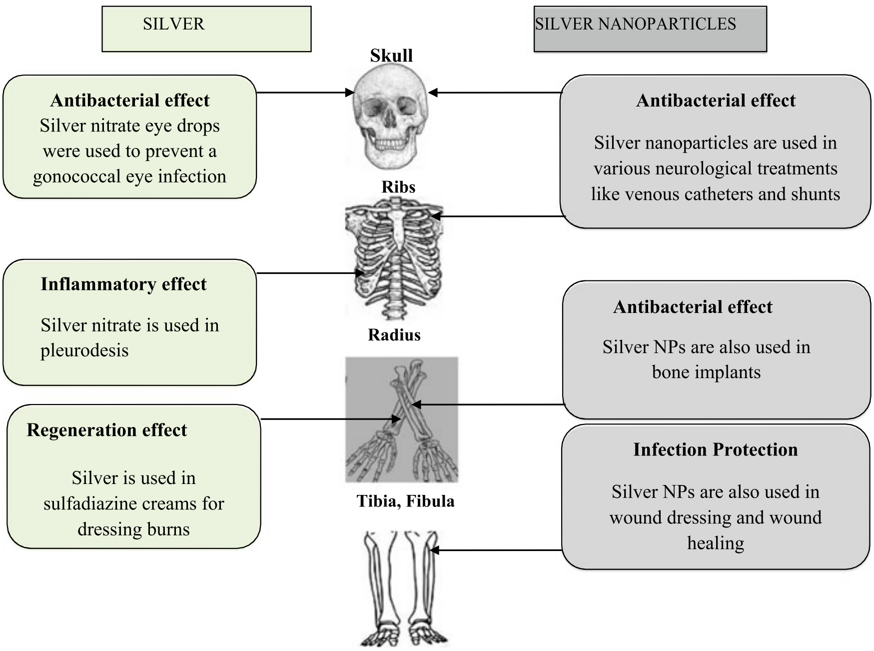

Fig. 4 Properties of silver nanoparticles

Fig. 5 Properties of gold nanoparticles

(c) **Zinc oxide nanoparticles (ZnO)**

Zinc is one of the most essential microelements. Owing to nano-dimension, the zinc particle ZnO acquires specific physical and chemical characteristics which are different from known metal compounds (Bogutska et al. 2013). Nanoscale zinc particles are typically 20–40 nm in size and are also available in 100 nm ranges. The ability of ZnO nanoparticles is to absorb a wide spectrum of radiation (ultraviolet, microwave, infrared, and at radio frequencies) that can be used for manufacturing cosmetic creams, ointments, and so on, which protect the organism from ultraviolet radiation. ZnO nanoparticles of 20–30 nm in size display antibacterial properties which are now used in the textile industry for producing fabrics for clothes. The formation of nanoparticles was monitored by SEM and FTIR spectroscopy.

(d) **Copper nanoparticles (Cu-NPs)**

Copper is a ductile metal, which has very high thermal and electrical conductivity. Cu-NPs show widespread applications because of their special properties like antibacterial activities, strong affinity, and strong catalysts activity. Cu-NPs have specific ligand binding activity with other nanoparticles because of their high surface area and volume ratio. Copper nanoparticles are round in shape and they appear as a brown to black powder and have various potential applications in the treatment of wastewater and radioactive waste by photochemical reactions.

(e) **Titanium dioxide nanoparticles (TiO_2 NPs)**

Recently, titanium dioxide nanoparticles are manufactured in large quantities because of its photostability properties. TiO_2 nanoparticles have the ability to block the ultraviolet radiation exposed by sun. Nowadays, TiO_2 nanoparticles are widely used in sunscreens to protect human skin by photo damage. They are widely used because of their high photocatalytic and photostability properties. In the medicinal field, TiO_2 nanoparticles play an important role in manufacturing of nanomedicine. TiO_2 NPs can also be used in the treatment of wastewaters, like clinical wastewater and hazardous industrial wastewater (Lusvardi et al. 2017). Recently, the biogenic titanium dioxide nanoparticles are most commonly used in advanced imaging and nanotherapeutics.

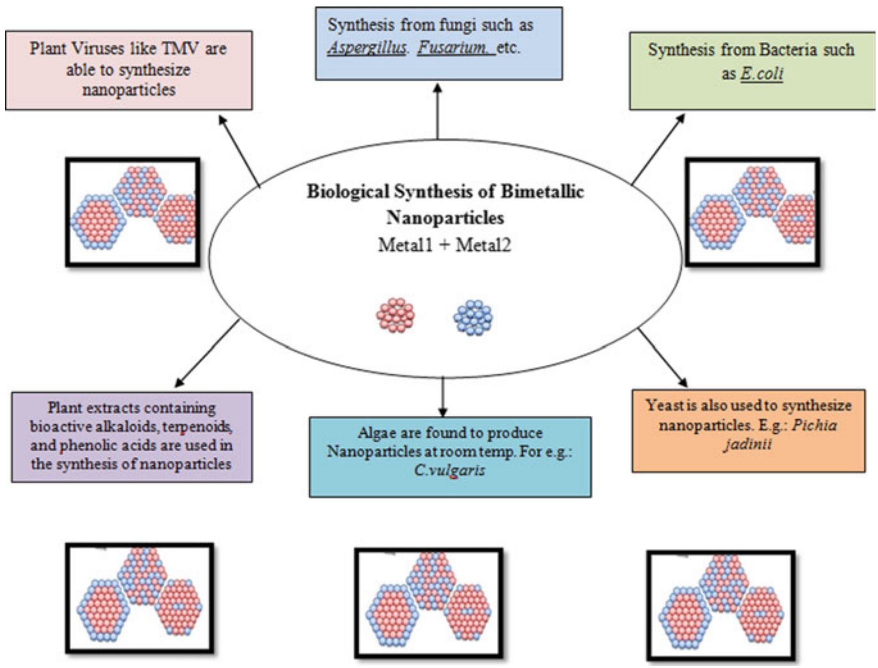

Fig. 6 Synthesis of bimetallic nanoparticles

2.2.2 Bimetallic Nanoparticles (BMNPs)

Syntheses of nanoparticles by a combination of two metal nanoparticles are termed as "bimetallic nanoparticles" (BMNPs) (Mazhar et al. 2017). In this type of nanoparticle, two metal nanoparticles have separate function to carry out overall reaction. Bimetallic nanoparticles have specific catalytic and selective activity than monometallic nanoparticles. Syntheses of bimetallic nanoparticles from different microorganisms were shown in Fig. 6.

There are several methods for the synthesis of bimetallic nanoparticles. The most commonly used methods are synchronous complexing method, sequential complex method, and partial substitution method. In synchronous method, two different metal ions are mixed with polymers to make bimetallic nanoparticles. The most commonly used bimetallic nanoparticles are shown in Fig. 7.

2.3 *Factors Influencing the Synthesis of Nanoparticles*

Various factors, such as temperature, pressure, pH, time, particle size, shape, and the concentration of the extracts, affect the synthesis and characterization of

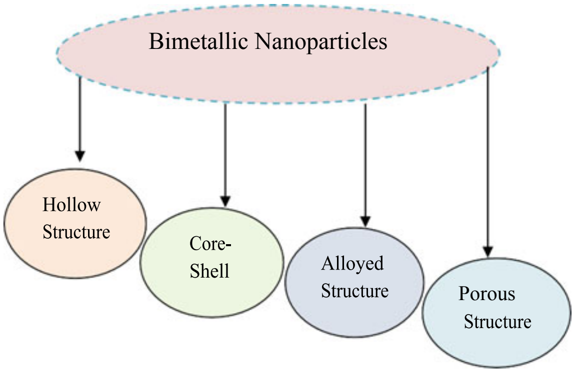

Fig. 7 Types of bimetallic nanoparticles

nanoparticles. Factors that influence the synthesis of nanoparticles are shown in Fig. 8.

1. **Mode of synthesis**: The synthesis of nanoparticles by physical and chemical methods includes mechanical protocols and various chemicals (organic and inorganic). The biological protocols involve natural products, respectively. The chemical and physical methods are very costly and their synthesized nanoparticles show several harmful effects on the environment. The biological modes of synthesis of nanoparticles are used widely because this mode of synthesis of nanoparticles is non-toxic and environmentally friendly in nature (Marchiol 2012; Patra and Baek 2014).
2. **pH**: pH is the most important and prominent factor for the synthesis of nanoparticles. It influences the size, texture, mode of synthesis of nanoparticles by alteration in the consistency of the media, or by altering the pH of the solution media.

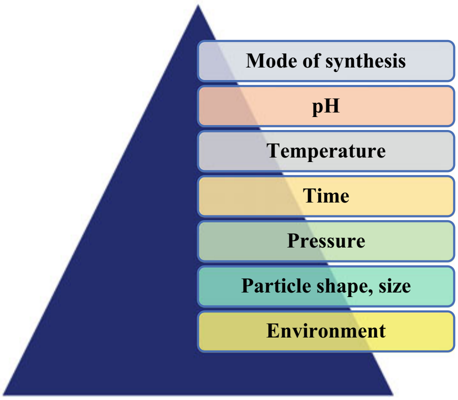

Fig. 8 Factors that influence the synthesis of nanoparticles

3. **Temperature**: Temperature is another influencing factor that affects the synthesis of nanoparticles. All three methods—physical, chemical, and biological—require the highest temperature for the synthesis of nanoparticles. The physical method requires at least 350 °C temperature and the chemical method requires less than 350 °C temperature. The synthesis of nanoparticles through biological system requires less than 100 °C temperature.
4. **Time**: Time influences properties and the characteristics of synthesized nanoparticles is the most important factor which influences the characteristics of nanoparticles. Variations in time affect the growth of nanoparticles, storage, and shelf life of the nanoparticles. The nanoparticles synthesized by biogenic approach are mainly influenced by incubation time.
5. **Pressure**: Pressure which is used for the reaction medium directly affects the size and shape of the nanoparticles.
6. **Particle Shape and Size**: Particle shape and size also play important role in the synthesis of nanoparticles. Properties of nanoparticles are based on accurate size and shape. Shape and size mainly affects the chemical properties of the nanoparticles.
7. **Environment**: Favorable environmental conditions determined the nature of the nanoparticles. Environment affects the physical and chemical properties of nanoparticles (Grillo et al. 2014; Hua et al. 2012; Ibrahim et al. 2016).

3 Characterization of Nanoparticles

Characterization means analysis of the materials, structure, composition, and physical–chemical properties. Characterization of nanoparticles is done by two most common methods: microscopy and spectroscopy.

Microscopy

1. Scanning electron microscopy (SEM)
2. Transmission electron microscopy (TEM)
3. Field emission scanning electron microscopy (FESEM)

Spectroscopy:

1. X-ray diffraction (XRD)
2. Ultraviolet spectroscopy (UV–Vis)
3. Fourier transform infrared spectroscopy (FTIR)

Characterization of nanoparticles is done by various techniques, like; SEM, TEM, FTIR, AFM, XRD, UV–Vis spectroscopy. These characterization techniques are most commonly used to determine the size, shape, structure, and surface area of the synthesized nanoparticles. Morphology and size of the nanoparticles are determined by TEM, SEM, and AFM (Choi et al. 2007). Summary of the experimental techniques that are used for nanoparticle characterization is shown in Table 1.

Table 1 Characterization techniques for nanoparticles

Techniques	Utility
Scanning electron microscopy (SEM)	Morphology/topology/imaging
Transmission electron microscopy (TEM)	Detect shape, size and localize NPs in matrices
UV–Vis spectroscopy (UV–Vis)	Optical properties, size, concentration
X-ray diffraction (XRD)	Crystal structure, composition
Fourier transform infrared spectroscopy (FTIR)	Surface composition, ligand binding
Field emission scanning electron microscopy (FESEM)	Topological information

(a) **Scanning electron microscopy (SEM)**

The basic principle of SEM is when the beam of electrons scattered on the surface of the specimen, they will interact with the atoms present in the samples. After the interaction SEM shows signals by generating backscattered electron or secondary electrons. The results were shown in the form of X-rays that gives the morphological and topological information of the samples.

Advantages	Disadvantages
Bulk samples can be observed	Samples must have surface electrical conductivity
Generates photo-like images	Time-consuming
Very high-resolution images	–

(b) **Transmission electron microscopy (TEM)**

TEM is another microscopy technique in which the beam of electrons passed through a thin specimen interacts with the samples. After the interaction of transmitted electrons and samples the result is shown by generating an image. These images are seen using CCD cameras or fluorescent screens.

Advantages	Disadvantages
Powerful magnification and resolution	Very expensive
Applied in various educational and scientific systems	Laborious sample preparation
Gives information of the elements and its structures	Require special trainings
Images are high-quality and detailed	Require special housing and maintenance

(c) **Field emission electron microscopy (FESEM)**

FESEM is a microscopic technique in which the microscope is used along with electrons. In this, the electrons are generated by field emission source and the specimen is scanned by electrons. After the interaction the results were shown in a zigzag pattern.

Advantages	Disadvantages
High-quality and low-voltage images	Very expensive
No need to add coatings on the materials	–

(d) **UV–visible spectroscopy (UV–Vis)**

It is a spectroscopic technique which absorbs both ultraviolet and visible lights. It follows Beer-Lambert law. It means when a beam of monochromatic light passed through a sample, the rate of radiation intensity and the thickness of the sample are directly proportional to the concentration of the sample.

Advantages	Disadvantages
Give extremely accurate readings	Spectra are not highly specific for particular molecules
Easy and simple to operate and inexpensive	Operation and analysis require special training

(e) **X-ray diffraction (XRD)**

X-ray diffraction is a method that determines the crystalline structures of the compounds. It is preliminarily used for crystalline materials. Analysis of the samples is done by X-rays. These X-rays are generated by cathode ray tubes present inside the XRD system.

XRD is an exclusive method in determination of crystallinity of a compound. It is mainly used for crystalline material. It differentiates amorphous and crystalline material. The analysis of XRD is based on constructive interference of monochromatic X-rays and a crystalline sample. The X-rays are generated in XRD analysis by cathode ray tube.

Advantages	Disadvantages
Least expensive	Size limitations
Best method to determine crystal structure	Low in sensitivity

(f) **Fourier transform infrared spectroscopy (FTIR)**

FTIR is another spectroscopy technique that determines the organic and inorganic components of the unknown mixture of the samples. The main purpose of FTIR analysis is to identify the chemical bonds present inside the samples.

Advantages	Disadvantages
Short measurement time	More expensive
Measures entire wavelength range	Cannot detect atoms or monoatomic ions
Better sensitivity	–

4 Applications of Nanoparticles

Nanotechnology is nowadays used as a most powerful tool in various fields. It rapidly gains importance toward the wide range of biomedical, industrial, and environmental applications. Latest applications of nanotechnology are shown in biogenic synthesis of nanoparticles. These biogenic nanoparticles show their advantages in biomedicinal to drug delivery systems and early disease detections, agriculture to crop protections, safe environment, safe water purifications, and solar energy systems. The synthesis of nanoparticles through biological methods will play a major role in many technologies because of its cost-effective, rapid synthesis, reasonable, and eco-friendly nature.

Today, the products manufactured by these biogenic nanomaterials have specific applications in the treatment of cancer, early disease detection, and diagnosis. There are another several widespread applications of these biogenic nanoparticles in wastewater purifications, pharmaceuticals, agriculture, and food products, which were shown in Fig. 9.

4.1 Biomedical Application of Biogenic Nanoparticles

(a) **Anticancer and drug delivery**

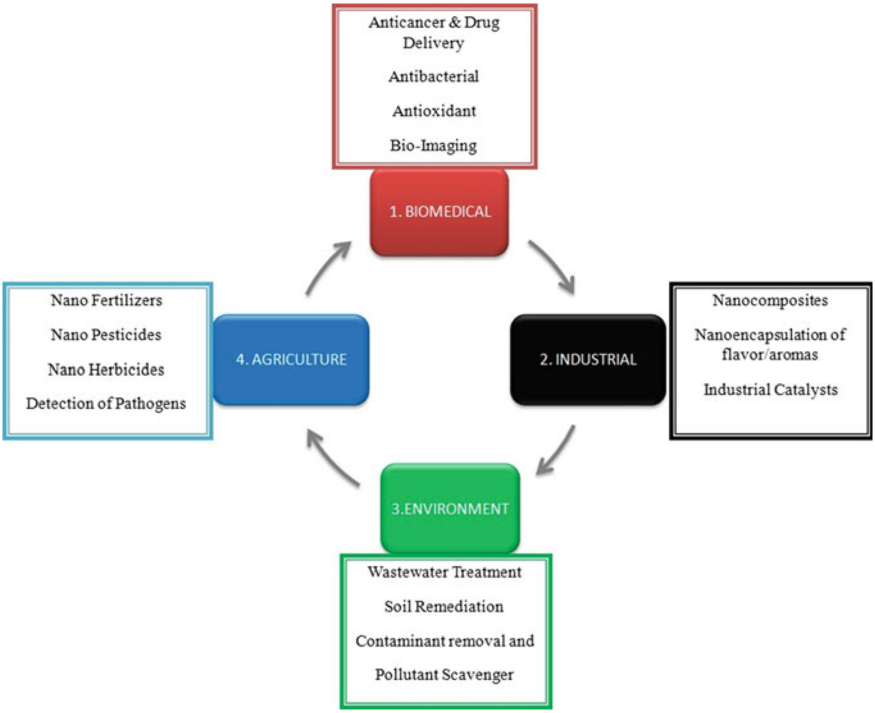

Fig. 9 Applications of nanotechnology in different fields

Biogenic nanoparticles are recently used in drug delivery and anticancer treatment because of their advantageous properties (Hong et al. 2006). The biogenic nanoparticles are designed as small so that they can be easily used as oral drug and for nanoencapsulations (Pandey and Khuller 2007). Gold and silver nanoparticles are the most commonly used nanoparticles in biomedical applications. Both gold and silver nanoparticles are capable of detecting and diagnosing the cancer.

Nanoparticles synthesized by physical and chemical methods are toxic in nature. These nanoparticles show various toxic side effects on human body. So there is a need to produce biogenic nanoparticles because of their cost-effective and eco-friendly in nature. Biogenic synthesis of metal nanoparticles provides cost-effective and safe therapeutics drugs for the treatment of cancer (Campbell et al. 2019; Chaloupka et al. 2010; Pandey and Khuller 2007). Nanoparticles like TiO_2, silica, and Au are used nowadays in the treatment of breast cancers. These nanoparticles have some specific ligand-binding characteristics that are capable in detecting the tumors in breast cancer images (Mu et al. 2017; Peng et al. 2014).

(b) **Antibacterial activities**

The biogenic synthesis of nanoparticles from microbial sources, like plants, bacteria, fungi, and so on, has become an emerging field due to simple, fast, eco-friendly, energy-efficient, and less toxic nature. The most commonly used microorganisms are fungi and bacteria that have higher potential antimicrobial activity against known pathogens. Silver nanoparticles are mainly used against the pathogenic bacteria because silver have specific biocidal activity. Nanoparticles synthesize endophytic fungus, *Pestalotia sp*, and the bacteria *S. aureus and S. typhi*. *Pseudomonas stutzeri AG259* was the first bacterial strain synthesized by nanoparticles (Chugh et al. 2018).

(c) **Bio-imaging and disease diagnosis**

Nanoparticle technology offers the possibility for characterization and imaging of tissues, lesion, and cells. Recently, in early disease detection, nanoparticles are used as a "biomarker". The biogenic synthesis of these biomarkers includes the synthesis of small peptides. These peptide biomarkers are sent into the cells at a particular location and after that they indicate the signals whether a disease is present or not (Campbell et al. 2019). These peptide biomarkers are also used in protein analysis, early disease detection, and tissue imaging (Cai et al. 2011; Vu et al. 2019).

4.2 Industrial Application of Biogenic Nanoparticles

a. **Nanocomposites**

Nanocomposites are a type of nanoparticles in which the nanoparticles are incorporated into a matrix to improve the properties of nanoparticles. These matrix-incorporated nanoparticles are termed as "nanocomposites". The carbon nanotubes are specific matrix materials which enhance the properties of nanoparticles (Katas et al. 2018). Some examples of nanocomposites are:

1. **Nanoshells**: Nanoshells are a type of nanocomposites that absorb the heat from infrared light and help in destroying the tumor cells.
2. **Nanotubes**: Nanotubes are a scaffold of polymer composites which helps in bone and joint replacement and repairing the structures of bones.
3. **Use of graphene to manufacture composites**: Addition of graphene (Campbell et al. 2019) to the composites is used to make the strong nanoparticle composites. These manufactured composites and its components have the higher strength-to-weight ratios.

b. **Nanoencapsulation of flavor and aromas**

Bio-nanocomposite or nanoencapsulation shows various applications in food and food-packaging materials. Use of flavors and aromas in food helps in preserving the food materials. Nanoencapsulation is an attractive and emerging technology that is recently used in food industries. Nanoencapsulation technique provides specific protection to the food compounds by essential oils, such as glycerol, phenol, and triglycerides (Mousavi and Rezaei 2011).

4.3 Environmental Application of Biogenic Nanoparticles

After meeting the major challenges in environment development and sustainability, the biogenic nanomaterials can help in solving serious environmental challenges in the area of wastewater treatment, pollutant removal, fatal diseases, climate change, and solar energy conversion. Nanoparticles are considered a good source for removal of many organic compounds due to their chemical stability, high oxidation efficiency, cheap, and are environmentally friendly (Ali Mansoori 2008; Bhavani et al. 2014; Cai et al. 2011; Hasan et al. 2016).

Some of the environment applications (Chaloupka et al. 2010; Chen and Schluesener 2008; Chen et al. 2014; Choi et al. 2007) of nanoparticles are:

a. **Biosensors**: Various nanoparticles, biogenic and non-biogenic, like oxide, metals are used in constructing of biosensors, and these nanoparticles play a major role in detecting and sensing systems (Sotiriou and Pratsinis 2011).
b. **Wastewater treatment**: Nanotechnology shows three types of advantages in the treatment of wastewater; majorly like treatment and remediation, sensing and detection, and pollution control. Cleaning of wastewater streams, contaminants that are toxic in nature, or those that are difficult-to-treat promised treatment of wastewater because these technologies are rapid, specific, and worthwhile solutions for the treatment of contaminants. Significant concerns also focused on soil remediation and groundwater sedimentation. Some latest examples of biogenic treatment of wastewater are nanocoagulants to extract water contaminants from wastewater streams. In this the Actinia-like biomimetic micellar nanocoagulant is recently used to treat groundwater. The major use of this technology is to remove contaminants from water and produce high-quality water (Liu et al. 2019).
c. **Nanomaterials for wastewater clean-up**: The titanate nanofibers are used as an absorbent for the removal of heavy metals or several radioactive ions from the wastewater. These types of nanoparticles are mostly used in the treatment of radioactive wastewater (Hua et al. 2012).
d. **Nanotechnology for battery recycling**: Batteries are yet containing different types of chemicals and hazardous heavy metals, like mercury, lead, copper, nickel, cadmium and so on, which defile the environment and cause several risks to human health when they are improperly disposed off. Recently, pure zinc oxide nanoparticles are used to form recyclable batteries. The Zn-MnO_2 alkaline batteries are used nowadays to save the environment (Bogutska et al. 2013).
e. **Hydrogen production from sunlight-artificial photosynthesis**: Hydrogen production from sunlight-artificial photosynthesis is green glow, ecological, and biodegradable technology that proves to be beneficial for our planet. In this system, the solar energy is used to break hydrogen and oxygen from water through artificial photosynthesis which can offer a clean and green advantageous root for energy supply from the sunlight (Melis 2012).

4.4 Agriculture Application of Biogenic Nanoparticles

Nanotechnology is a highly probable technology that will help to recast agricultural operations (Mousavi SR, Rezaei 2011; Pérez-de-Luque and Rubiales 2009; Prasad et al. 2017; Sekhon 2014; Singh et al. 2015). In agriculture, it will show highly fruitful results in controlling fertilizers, nutrient suppliers, and also for sustainable development (Gruère 2012; He et al. 2018). The implication of the nanotechnology research in the agricultural sector is becoming to be necessary, and is even a key factor for sustainable development. Abiogenic nanoparticles, like titanium, zinc, are proved as good in resource management of agricultural field, drug-delivery mechanisms in plants, and help to maintain the fertility of the soil. Mainly, zinc oxide nanoparticles are used to enhance the growth of fertilizers and food crops by making zinc oxide colloidal solutions.

a. **Nanofertilizers**

Nanofertilizers are nutrient-rich fertilizers that supply nutrients to the soil and plants to revive the fertility of the soil. The nanofertilizers are freely available in the market in the last few years. They will help to maintain the plant growth and sustainability of soil. The main advantage of nanofertilizers is that they can be used in very small amount for the growth of plants (Wang et al. 2016).

b. **Nanopesticides**

Nanoparticles also play a major role in the control of pests and insecticides. Nanoencapsulation method is used to make nanopesticides. These nanopesticides have special properties, like soil solubility, specificity, and permeability (Bhattacharyya et al. 2016). These nanoencapsulated pesticides are used most commonly because of their slow releasing properties in the soil which make them suitable and sustainable for environment. The advantage of these nanopesticides is to develop non-toxic pesticide to enhance the growth of plants.

c. **Nanoherbicides**

Economic losses in crop yields and sustainability by weeds cause a serious problem in agriculture. Because of this serious problem, it is necessary to eliminate weeds from environment. Nanoherbicides are eco-friendly and cost-effective approach to protect the environment from wild weeds (Pérez-de-Luque and Rubiales 2009). Nanoherbicides are mixed with groundwater because of their high surface to volume ratio which provides a strong interaction with soil. Grillo obtained (Grillo et al. 2014) chitosan/tripolyphosphate nanoparticles and used as a carrier system to remove herbicides from the environment.

d. **Agriculture: Crop protection and livestock productivity**

In agricultural activities, nanotechnology shows a significant concern because their nano-sized particles help in increasing the crop productivity and in enhancing live stock quality. Nanotechnology in agriculture is a most efficient and sustainable application that will help to protect the plant growth from toxic chemicals and detect the plant diseases. It is also used to enhance the food production and quality of food (Sekhon 2014).

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