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REVIEW ARTICLE

Microorganism assisted synthesized nanoparticles

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ABSTRACT

Nanoparticles are used in a number of fields, including antimicrobials, additives, paints, biosensors, and cosmetics. Because of their multifunctional property and intrinsic molecular property, inorganic nanoplatforms are an appealing tool in a range of biomedical applications. They assist in efficient diagnosis, imaging, continuous monitoring, and successful therapy. Bio-reduction of inorganic nanoparticles (INPs) using bacteria and other microorganisms has recently gained popularity due to several advantages over chemical synthesis methods, including low cost, fewer toxic chemicals used, biocompatibility, and ease of synthesising. The use of microbes is an excellent way to deal with the development of environmentally safe and cost-effective nanoparticles. Advancement of nanoparticles union by improved generation of society growth will provide a strong opportunity for the most extreme manufacture, and it will be extremely useful for a variety of nanoparticles-based applications.

INTRODUCTION

Nanoscience and nanotechnology have ignited a lot of interest in recent years because of their potential impact on a number of logical fields, including power, path, pharmaceutical commercial enterprises, hardware, and space businesses [1]. This innovation deals with small structures and materials with dimensions varying from a few nanometers to less than 100 nanometers. Because of their broad surface-to-volume ratio, NPs have special and extensively modified substance, physical, and organic properties as compared to other parts of the same synthetic organization [2].

Morphology of Nanoparticles

The morphological uniqueness of nanoparticles is: flatness and aspect ratio.

1. High aspect ratio NPs.
2. 2- Small aspect ratio NPs.

Nanomaterials Types

Natural, inorganic, and composite NMs are all feasible. Natural nanomaterials include proteins, nucleic acids, and carbon nanotubes, among other things. Inorganic nanomaterials, on the other hand, include metallic NPs, blends, and mass nano-organized materials. Ag, Au, Pd, and Pt are the metallic nanomaterials in question. Bimetallic nanoparticles such as Ag-Pt, AgAu, Pd-Au, Ti [TiO2], Fe [Fe2O3-] magnetite, Fe3O4-magnetite, Zn [ZnO], Si [SiO2], and sulphides of different metals [CdS, FeS, ZnS] are also included. Mass nano-organized metals, precious stones, and powders of Te, Ti, Se, Al, and transfer metals like Ni, Co, Cu, Cr, Zr, and Pb are among the various nanomaterials. Quantum dots, carbon nanotubes, nanoshells, nanobars, nanowires, nanogels, and nanoemulsions are examples of nano-composite materials. Nanoparticles can be categorised according to their dimensions, such as zero-dimensional iota groups, one-dimensional governed multilayered, two-dimensional NPs, and three-dimensional, ultra-fine grained over layers [3].

Properties of Nanomaterials

In view of the fact that no strong can be prepared smaller than it, the nanoscale is special. It's also interesting in light of the fact that many components of the physico-synthetic and natural environment can be calculated on scales ranging

from 0.1 nm to 100 nm. The reduction in particle size, on the whole, increases the surface to volume ratio of the particles, enhancing their reactivity [4].

Synthesis of Nanomaterials

The nanomaterials synthesis involves chemical, physical and biological methods. Biological procedures are still in the stage of development.

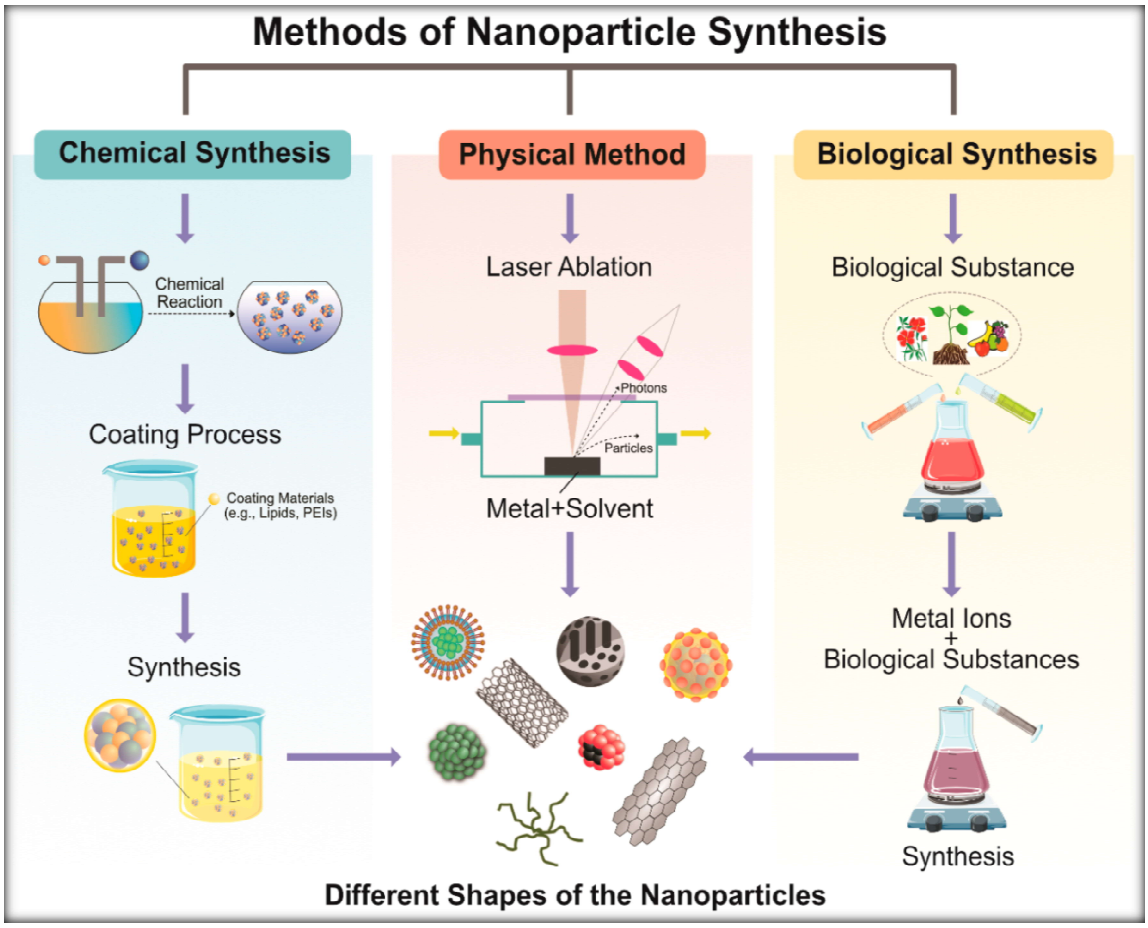

Figure 1: Methods of Nanoparticle Synthesis

Physical and Chemical Synthesis of Nanomaterials

Crushing, physical vapour deposition (PVD), ball sorting, lithography, and pyrolysis are all physical methods for mixing nanomaterials. The most popular methods used have been pounding and pyrolysis. Although substance systems such as electrolysis, sputtering, sol gel synthesis, CVD (chemical vapour deposition), sputtering, and inactive gas buildup have become more mainstream, there should be an occurrence of substance systems such as electrolysis, sputtering, sol gel synthesis, CVD (chemical vapour deposition), sputtering, and inactive gas buildup. These methods are beneficial, but they are also harmful and costly [5].

Biological Synthesis of Nanomaterials

Plants and microbes such as yeast, fungi, bacteria, and actinomycetes are biological sources. Biological sources have been discovered to reduce metal ions in the soil. In contrast to other physical and chemical processes, this process is very safe. Although these methods produce nanomaterials with a lower concentration of energy, the nanomaterials produced by these methods have proven to be very reactive. This "enzymatic" idea is made even more plausible by the fact that most microorganisms evolve in response to changes in temperature and pH [6].

Why Choose Bacteria?

Nanoparticles are being researched and produced all the time. The nanomaterials are made using three different methods. Lithography, pyrolysis, and vapour pressure are examples of physical methods, but they are all very costly.

Table 1: Advantaged and disadvantages of different techniques

Technique	Advantages	Disadvantages	Chemicals/ Microorganims Used
Physical		Firm enter, befuddled by data, and the efficacy note being of NPs Delivery of crystal expansion, particle synthesis	
Chemical	High monodispersity (5–15%)	As a consequence of the expense of feeble-mindedness in figure and sortie, argument of mortal chemicals has been made. Notice that the world ironmental is simple to deal with in terms of NP resolution. Controlling the crystallisation process and particle synthesis Yield is low.	Reducing agents, such as methoxypolyethylene glycol, sodium borohydride, potassiumbitartarate, hydrazine Stabilizing agents, such as polyvinyl pyrrolidone, sodium dodecylbenzyl sulfate.
Biological	Low monodispersity (~40–50%), environmental friendly	Yeast, bacteria, fungi, algae, plants, viruses and actinomycetes.	

Table 2: Microorganisms involve in the synthesis of different NPs.

Biological Entity	Microorganisms	Types of NPs synthesized
Bacteria 1 nm–200 nm diameter	Bacillus licheniformis; Bacillus subtilis; Bacillus stearothermophilus; Clostridium thermoaceticum; Desulfobacteriaceae; E. coli; Klebsiella aerogenes; Klebsiella pneumonia; Lactobacillus increase; Rhodopseudomonas capsulata; Magnetospirillum magnetotacticum; Desulfovibrio desulfuricans; Pseudomonas aeruginosa; Pseudomonas stutzeri AG259; Rhodopseudomonas palustris; Thermoanaerobacter ethanolicus (TOR-39)	Ag, Au, CdS, pd, Fe3O4, ZnS

Physical and chemical methods have low yields, are energy intensive, difficult to scale up, often generate high levels of hazardous wastes, and can necessitate the use of expensive precursors. Furthermore, chemical methods include irradiation reduction, micro-emulsion reduction, and electrochemical reduction; however, chemical methods are very risky, and this synthesis can still result in the presence of certain lethal chemical species adsorbed on the surface, which could have unfavourable effects in medical applications. As a result, low-cost, safe, non-lethal, and environmentally friendly synthesis methods are required. As a result, researchers turned to biological systems for inspiration in nanoparticle synthesis last year. Even though microorganisms have many biotechnological applications, such as the remediation of lethal metals, they have recently been discovered as potential environmentally friendly nanofactories. It has been verified that prokaryotes earnestly function as nanoparticle synthesisers.

Bacteria are a good choice for research because of their abundance in the ecosystem and their ability to adapt to the original broadcasting situation. Bacteria are also still maturing, inexpensive to grow, and simple to manage. Diffusion parameters such as oxygenation, incubation time, and temperature can all be easily modified. It was discovered that irregular pH of the collecting activity by incubation resulted in the play of nanoparticles of incompatible display and suit; however, such transfer is normal, as unconditional morphologies of NPs are needed for various applications such as catalysts, optics, and antimicrobials [7].

NPs synthesis by bacteria

Bacteria have a remarkable capacity to reduce heavy metals and nanomaterials, as well as synthesise them. Some bacteria have evolved the ability to react to unique defence mechanisms in order to control stresses such as nanomaterial toxicity. Prokaryotes have gained a lot of attention in research as a way to make nanoparticles. Bacteria are a good choice for learning because of their abundance in the atmosphere and their ability to adapt to extreme conditions. They're also quick-growing, low-cost to produce, and simple to manage. Temperature, oxygenation, and incubation time can all be easily controlled during development [8].

Table 3: Bacteria involve in synthesis of different nanoparticle

Bacteria	Nanoparticle	Size	Morphology
Aeromonas sp. SH10	Silver	6.4	
Bacillus Cereus	Silver	20–40	Spherical
Bacillus megatherium D01	Gold	1.9 ± 0.8	Spherical
Bacillus subtilis	Silver	5–50	Triangular and spherical
Clostridium thermoaceticum	Cadmium sulfide		Amorphous
Desulfobacteraceae	Zinc sulfide	2–5	Spherical
Desulfovibrio (desulfuricans,vulgaris, magneticus strain RS-1)	Palladium, selenium, gold, uranium, chromium and magnetite	Up to 30	Crystalline

Synthesis Types

Synthesis is of two types; intracellular and extracellular.

Intracellular Nanosynthesis

A large number of bacterial species have been studied for intracellular bio-nanosynthesis of metallic and non-metallic nanoparticles;

1. Intracellular Synthesis of Metallic Nanomaterials

Intracellular metal nanoparticles have been reported as bio-nanofactories in a variety of microorganisms. In general, both bacterial synthesis and biogeochemical cycles have played an important role. This skill has aided them in moving between various mixes and simple metal in nature. Microscopic species detoxify highly lethal metal particles by lessening or oxidation, precipitation or complexation, transportation or efflux structures, and so on. These characteristics have placed them as potential bioremediation experts in both soil and oceanic environments. In this light, the role of microscopic organisms in the biogenesis of nanoparticles has also been explained in recent decades. The synthesis of intracellular metal nanoparticles such as gold, silver, gold-silver alloy, platinum, palladium, and uranium has been studied in a few bacterial strains in this way [9].

- **Gold Nanoparticles**

Bacillus subtilis 168 encouraged gold (Au+3) particles to Au0 nanoparticles with octahedral morphology has been accounted for onto their cell dividers. Another bacterium, Geobacter ferrireducens diminished Au particles in periplasmic space to deliver AuNPs. Shewanella algae likewise decreased Au+3 particles to natural AuNPs at 25°C in periplasmic space and on its cell surface. Under various pH conditions distinctive sizes of NPs were watched. Plectonema boryanum UTEX485, a cyanobacterium, developed AuNPs at 25 to 200°C with the aid of external layer proteins, lipopolysaccharides, and phospholipids. In microscopic species, this blend has been related to unique detoxification systems. Round, triangular, or hexagonal AuNPs have been bio-diminished the cell surface in E. coli DH5 with different morphologies. Furthermore, the biosynthesis of AuNPs in Rhodobacter capsulatus has been linked to plasma layer-related NADPH-subordinate proteins and carotenoids [3].

- **Silver Nanoparticles:**

AgNPs synthesis has been related to bacterial cell surfaces in general. If Pseudomonas stutzeri AG259 crystalline silver sulphide acanthite (Ag2S) was found in the periplasmic space, the morphologies were monoclinic, triangular, equilateral, and hexagonal. It was linked to cell surfaces in Lactobacillus sp. A09 at 30°C, which were first linked to biosorption and then reduced Ag+ particles to form AgNPs. The nucleation destinations for AgNPs are thought to be provided by silver-restricting proteins that have amino corrosive moieties. AG3 and AG4 stimulated the growth of silver precious stones with a face-focused cubic morphology (silver encouraging peptides). In addition, Bacillus sp. incorporated AgNPs into its periplasmic space. This accumulation or precipitation of Ag at the cell divider at 60°C has also been thought to be a detoxification mechanism assisted by periplasmic proteins.

- **Magnetic Nanomaterials:**

Different microscopic organisms, such as Aquaspirillum magnetotacticum, Magnetospirullum magnetotacticum, M. magnetotacticum MS-1, M. gryphiswaldense, Candidatus Magnetoglobus multicellularis, Magnetotactic bacterium MV-1, and Sulfate decreasing microscopic organisms, were observed to demonstrate intracellular bacterial

biosynthesis of attractive nanocrystals of magnetite. Magnetotactic microorganisms, which have special structures called magnetosomes in their phones, contain biomineralized magnetite NPs. These magnetotactic microscopic species live in marine and freshwater silt, providing intracellular, layer bound magnetite, pyrrhotite, ferromagnetic iron sulphide, greigite (Fe3S4), and non-attractive minerals (e.g. iron pyrite) as chains. Using high-angle attractive separators, the attractive NPs are removed from the structure. Magnetosomes manufacture crystalline and non-crystalline attractive nanocrystals in a variety of morphologies, including octahedral, highly sought single or different chains, unpredictable faceted cub-octahedral form, parallelepiped, octahedral, or hexagonal crystal-like forms, which are tethered and collected in microbe phospholipid layers [10].

- **Sulphide Nanomaterials:**

Different microorganisms, including Klebsiella pneumoniae, Clostridium thermoaceticum, and E. coli, incorporated semiconductor nanocrystals of cadmium sulphide (CdS) intracellularly. CdS nanocrystals were found to be accelerated by cysteine desulfhydrase activity, which induced cysteine desulfhydration on cell surfaces or in the medium. The optical and photoactive properties of these bio-interceded semiconductor CdS nanoparticles revealed round and circular shapes. In another research, species belonging to the Desulfobacteriaceae family naturally orchestrated round ZnS NPs.

2. Non-metallic Nanomaterials

Non-metal bionanosynthesis, such as that of selenium, has also been studied. Different microscopic species, including Stenotrophomonas maltophilia SELTE02, Enterobacter cloacea SLD1a-1, Rhodospirullum rubrum, Desulfovibrio desulfuricans, E. coli [30], P. stutzeri, Tetrathiobacter kashmirensis, and P. aeruginosa SNT1, have been found to store selenium NPs [11].

Table 4: Intracellular synthesis of nanoparticles by bacteria

Organism	Metal/Non-metal	Size (nm)	Location of synthesis	Shapes
Idiomarina spp. PR58-8	Ag	26	Intracellular	
Pseudomonas spp	Ag	156-265	Intracellular	
Bacillus subtilis 168	Au	5–25	Intracellular	Octahedral
Shewanella algae	Au	10-20	Intracellular	
Plectonema boryanum UTEX485	Au	10	Intracellular	Cubic
Escherichia coli DH5α	Au		Intracellular	Spherical

Extracellular Nanosynthesis

A number of bacteria have been studied for their potential of extracellular bionanosynthesis.

Extracellular Synthesis of Metallic Nanomaterials

- **Gold Nanoparticles:**

At room temperature, Rhodopseudomonas capsulata observed bioreduction of Au+3 into metallic AuNPs. Round and triangular morphologies were used to construct the particles. The pH division of the answer mixture showed the arrangement of different sizes and states of these NPs [12].

- **Silver Nanoparticles:**

Aeromonas sp. SH10 dried cells. were used to deliver mono dispersed AgNPs of uniform size and protection. Bioreduction of silver (Ag+) particles to metallic Ag0 by the operation of society supernatants of *E. coli,* Enterobacter cloacae, and Klebsiella pneumoniae showed a rapid combination of AgNPs. When piperitone was applied to the response blend, bioreduction was inhibited, suggesting the existence of nitro-reductase. B. licheniformis was also found to have extracellular AgNP amalgamation [12].

Table 5: Extracellular synthesis of nanoparticles

Organisms	NPs	Synthesis location	Method
Thermomonospora sp.	Au	Extracellular	Reduction
Escherichia coli	Pd, Pt	Extracellular	Reduction
Rhodopseudomonas capsulata	Au	Extracellular	Reduction
Pseudomonas aeruginosa	Au	Extracellular	Reduction

Applications

1. Multidisciplinary in Nature

In terms of research and applications, nanotechnology is a multidisciplinary field. In the last few decades, research in architecture, physical science, natural chemistry, and microscopy has resulted in major increases in interest in representing small particles and their possible effects in different fields of material science. Improve the analytic and treatment methods. In terms of research and applications, nanotechnology is a multidisciplinary field. In the last few decades, research in architecture, physical science, natural chemistry, and microscopy has resulted in major increases in interest in representing small particles and their possible effects in different fields of material science. Improve the analytic and treatment methods [13-14].

2. Nano-Biomedicine

In nano-biomedicine, discrete NMs are widely used as fluorescent natural labels and middle people for prescription and drug distribution. They can also be used for pathogen identification, tissue architecture, tumour destruction, contrast shift in magnetic resonance imaging (MRI), and phagokinetic studies.

3. Incomprehensible as Antimicrobial

AgNPs have been commonly used in surgical gloves and covers, antibacterial injury dressings, bed lines, and other applications. They also have a number of uses in the fields of gadgets, catalysis, and diagnostic therapeutics.

4. Biosensors

Similarly, gold nanoparticles (AuNPs) are used for a number of purposes, including marking biosensors, treating hyperthermia, and transporting large quantities of biomolecules. They include non-dangerous approaches to quality and drug distribution to target locations [15].

5. Clinical Operations

In vivo indication of NPs in helpful capacities is becoming more common in clinical operations these days. While there are some ambiguities regarding the configuration and repercussions of NMs, such as their pharmacokinetics, transport in the body, poisonous consistency, and protection evaluation prior to and after their conjugation in therapeutic methods, there are still some. As a result, the biosimilarity of these NMs is still uncertain, and distinct planning studies are ongoing to keep a healthy distance from these adverse effects. AuNPs are currently widely used in healing and imaging procedures, owing to their nontoxic nature.

6. For Cancer Therapy

The increased biosynthesis of NPs could be the result of optimization. On the quinine aspects, such as types of organisms, hereditary and genetical offering of organisms, incomparable publication for partition collecting and enzyme activity, optimal counteraction issuance, and selection of the biocatalyst state, methodical protocols could be used for alloying of distinctly definite and well-characterized NPs right away on the quinine aspects, such as types of organisms, hereditary and genetical offering of organisms, incomparable publication for partition collecting and enzyme. By monitoring the prior reaction conditions, the morphology of the NPs depths is comfortable. Harvesting the cells made up of NPs by adding metal ions to the cells, breaking the cells by classiness, homogenization of the cells to separate the generated NPs, stabilisation of the NPs, product formulation, and quality control are all processes that must be carried out on an industrial scale [16].

Future Prospects

Time-consuming purification steps and a lack of knowledge of the mechanisms are two major disadvantages of bacteria-based NP biosynthesis. Controlling the shape and size of the particles, as well as achieving monodispersity in the solution process, are two major challenges in the biosynthesis of NPs. Before this green bio-based approach can be an effective and competitive alternative for industrial NP synthesis, it appears that many significant technological challenges must be addressed. Scaling up for production-level processing is a major challenge [17]. Furthermore, little is known about the mechanistic aspects of nanoparticle biosynthesis, and this information is required for the efficient and rational development of nanoparticle biosynthesis. The most important factors in the process of developing well-characterized NPs are as follows:

- **Selection of the Best Bacteria**

Researchers focused on some important intrinsic properties of bacteria, such as growth rate, enzyme activities, and biochemical pathways, in order to select the best candidates. The application we expect from the NPs we produce

determines which candidate is best for nanoparticle production. For example, it may be necessary to synthesise NPs with smaller sizes or unique shapes, or it may be necessary to synthesise NPs in a shorter period of time.

- **Selection of the Biocatalyst State**

The main agents in nanoparticle synthesis tend to be bacterial enzymes (biocatalysts). Whole cells, crude enzymes, and refined enzymes can all be used as biocatalysts. Using culture supernatant or cell extract appears to have the ability to speed up the reaction. These NPs, however, did not demonstrate long-term stability. Furthermore, in the case of intracellularly derived NPs, the release of NPs from the cells was an important factor to consider. The majority of the reactions that produce nanoparticles tend to be bioreductions. The coenzymes (e.g., NADH, NADPH, FAD, etc.) must be supplied in stoichiometric quantities in bioreduction processes. Since whole cells are more costly, they are favoured because the coenzymes are recycled during the pathways in live whole cells [18].

- **Optimal Conditions for Cell Growth and Enzyme Activity**

We need to produce more enzymes, which can be accomplished by increasing biomass synthesis. As a result, optimising the growth conditions is critical. It's necessary to optimise the nutrients, inoculum size, pH, light, temperature, buffer power, and mixing pace. Induction of the related enzymes appears to be essential as well. The activity would be increased if the substrates or related compounds were present in subtoxic levels from the start of the development. When using whole cells and crude enzymes, the harvesting time is crucial. As a consequence, monitoring enzyme activity during the growth process may be important.

- **Optimal Reaction Conditions**

To prevent adverse reactions and provide a cleaner medium for better and simpler study, it is desirable to harvest the cells (biocatalysts) to extract unnecessary residual nutrients and metabolites. The yield and production rate are important factors to consider when using bacteria to synthesise nanoparticles on an industrial scale. As a result, the bioreduction conditions in the reaction mixture must be optimised. The substrate concentration (to maintain the biocatalyst at a safe level), biocatalyst concentration, electron donor concentration, exposure time, pH, temperature, buffer power, mixing speed, and light must all be optimised. The researchers used some complementary factors like visible light or microwave irradiation, as well as boiling, to influence the morphology, duration, and rate of the reaction. Highly stable NPs with ideal sizes and morphologies appear to be achievable by optimising these essential parameters. Purification, isolation, and stabilisation of the generated NPs are also crucial, and challenges must be overcome in this area. Researchers have concentrated their efforts on determining the best reaction conditions and cellular pathways for metal ion bioreduction and NP synthesis.

- **Extraction and Purification Processes**

The extraction and purification of metal NPs developed by bacteria (intercellular or extracellular synthesis) for further applications is not well known, but research is underway to resolve these issues and find the best solutions. Additional processing steps, such as ultrasound treatment or reaction with appropriate detergents, are needed to release the intracellularly formed NPs. This can be used to extract valuable metals from mine wastes and metal leachates. Metal NPs that have been biomatrixed may be used as catalysts in a number of chemical reactions. This will assist in the retention of NPs for long-term use in bioreactors. To remove the produced NPs from the cells, physicochemical methods such as freeze-thawing, heating processes, and osmotic shock can be used. However, it appears that these methods can disrupt the structure of NPs, resulting in aggregation, precipitation, and sedimentation. This could alter the shape and size of NPs, interfering with their suitability. Furthermore, enzymatic lysis of microbial cells containing intracellular NPs may be used, but this process is costly and unsuitable for up-scaling and industrial NP production. Surfactants and organic solvents tend to be ideal for both NP extraction and stabilisation, but these chemicals are toxic, costly, and risky. It should be noted that in the case of extracellular nanoparticle processing, a centrifuge may be used to extract and purify NPs, but aggregation could occur [19].

- **Stabilization of the Produced NPs**

Researchers found that the NPs developed by these environmentally friendly bio-based approaches had an interesting stability, with no aggregations, even after being stored at room temperature for several weeks. The

microorganisms' secreted proteins and enzymes may be responsible for the NPs' stability. As a result, it appears that these environmentally friendly methods can be used to render highly stable NPs.

- **Scaling up the Laboratory Process to the Industrial Scale**

The optimization of reaction conditions may result in improved NP biosynthesis. When critical aspects such as types of species, inheritable and genetic properties of organisms, ideal conditions for cell growth and enzyme activity, optimal reaction conditions, and selection of the biocatalyst state have been considered, biological protocols could be used for the synthesis of highly stable and well-characterized NPs. By altering the aforementioned reaction conditions, the size and morphology of the NPs can be regulated (optimal reaction conditions section). Crop culture, inoculation of the seed into the biomass, harvesting the cells, synthesis of NPs by adding metal ions to the cells, separation of cells by filtration, homogenization of the cells to isolate the generated NPs, stabilisation of the NPs, product formulation, and quality control are some of the processes needed for industrial scale synthesis of metal NPs using biomass [20-22].

CONCLUSION

Microbial entities have formed and evolved in environments containing different inorganic materials since the beginning of life on Earth, and these microorganisms play an important role in the transition of minerals from one type to another in nature. Furthermore, a large number of minerals are needed for the survival of life on Earth. Multidisciplinary approaches to inorganic nanoparticles synthesised by microorganisms through intracellular or extracellular routes have been found in a plethora of literatures. These nanoparticles have now developed themselves as a common medium for a wide range of biological applications in a more effective and environmentally friendly manner than chemical and physical methods involving hazardous chemicals and high temperatures, which are not only harmful to the environment but also expensive. Furthermore, greener synthesis of nanoparticles is favoured over physico-chemical methods because it is more environmentally friendly, sustainable, healthy, and ecofriendly. As mentioned in this chapter, various microbial groups have concentrated on alternative ways of synthesising nanoparticles, from approaches to applications. Still, the field of microbial biosynthesis of metallic nanoparticles is relatively new and underexplored; however, it shows great promise in the development of newer technology because it provides a single-step process for nanoparticle biosynthesis, attracting more researchers to pursue future developments in the areas of electrochemical sensors, biosensors, healthcare, pharmaceuticals, and environmental protection. Improved technology will certainly open offers a wider of new and exciting possibilities in the application of bioprocessed nanoparticles in all aspects of life, which will be a boon to society.

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