Biological Synthesis of Nanocatalysts

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Many well-established methods are extensively utilized for the synthesis of nanocatalysts. However, most conventional physical and chemical methods have some drawbacks, such as the toxicity of precursor materials, the requirement of high-temperature environments, and the high cost of synthesis, which ultimately hinder their fruitful applications in various fields. Bioinspired synthesis is eco-friendly, cost-effective, and requires a low energy/temperature ambient. Various microorganisms such as bacteria, fungi, and algae are used as nano-factories and can provide a novel method for the synthesis of different types of nanocatalysts. The synthesized nanocatalysts can be further utilized in various applications such as the removal of heavy metals, treatment of industrial effluents, fabrication of materials with unique properties, biomedical, and biosensors.

green source nanocatalysts nanoparticles bacteria fungi algae

1. Introduction

Nanotechnology has evolved as a highly technical research arena with potential applications in all spheres of life. The term "nano" has been derived from the Greek for "dwarf." With a clear idea of the extremity of something in a nano, a nanoparticle can be defined as particles that have at least one dimension below 100 nm [1]. Several bulk materials show completely different properties when they are studied on the nanoscale. One known reason for this phenomenon is their higher surface-to-volume aspect ratio. For different nanoparticles, this can result in a variety of characteristics. For example, the higher aspect ratio of silver nanoparticles allows them to have increased efficacy in antibacterial properties. Consequently, silver nanoparticles can have diverse applications in cosmetics, packaging, electronics, coatings, and biotechnology [2][3]. A unique property of nanoparticles is that they have the ability to combine or form a solid at lower temperatures without melting. This property helps to achieve improved coatings on capacitors and other electronic components. Nanoparticles are also transparent, which allows them to be utilized in packaging, coating, and cosmetics (e.g., scratchproof eyeglasses, crack-resistant paints). When metallic nanoparticles are attached to single-stranded DNA, they can travel through the bloodstream and confine any target organ. This characteristic can be exploited in medical diagnostics, therapeutics, and other biomedical applications. Due to their significant potentials, nanoparticles must be further studied to find unexplored uses in everyday life [4].

Nanocatalysts are usually differentiated based on their dimension, composition, morphology, material nature, agglomeration, and uniformity. The morphology and shape of nanoparticles have vital functions, such as their toxic effect on mankind or the environment [5]. On the basis of dimension, nanoparticles can be one-dimensional, two-dimensional, and three-dimensional. Thin-film coatings used in sensors and electronic devices come under 1D, whereas carbon nanotubes, wires, fibers, etc. belong to 2D nanoparticles. Three dimensional nanoparticles include quantum dots, hollow spheres, and dendrimers. On the basis of morphology, they can be spherical, flat, crystalline, cubic, etc. structures and present in either single or composite form.

Numerous physical and chemical approaches can be effectively utilized for nanocatalyst synthesis. These include aerosol technologies, microemulsion, microwave, laser ablation, lithography, photochemical reduction, ion sputtering, sol–gel, sonochemical, ultrasonic spark discharge, and template synthesis [6]. However, most approaches have some nonnegligible drawbacks as these processes use expensive and hazardous chemicals and consume a lot of energy. Chemical synthesis has proved to be useful and can be used for a long time, but they have certain demerits such as the aggregation of particles when allowed to react for a long time, instability of the final product, and improper control of crystal growth [7]. Moreover, this method is not environmentally friendly, as a lot of toxic wastes and pollutants are generated as by-products. In particular, both physical and chemical techniques produce harmful pollutants such as harmful capping and reducing agents and organic solvents. Therefore, the use of harmful chemicals and organic solvents involved in nanomaterial synthesis should be reduced [8]. Hence, both conventional methods of nanoparticle synthesis, i.e., physical and chemical methods, have evolved as costly and are not friendly to the ecosystem. The demerits of these methods lead to the development of novel methods for the synthesis of nanomaterials that should be environmentally friendly, cheap, nonhazardous, clean, and energy-efficient [9]. Recently, the focus has shifted to the utilization of biological agents for the synthesis of nanomaterials due to their various advantages as compared to chemical and physical ones. Biological methods of synthesis are generally utilized by biological entities such as algae, fungi, and bacteria [10].

There are different groups of nanoparticles available, which include carbon-based nanoparticles, ceramic nanoparticles, semiconductor nanoparticles, metal/metal oxide nanoparticles, and polymeric nanoparticles [11][12][13][14][15][16][17]. Metal/metal oxide nanoparticles have gained significant interest due to their wide range of applications such as the detection and imaging of biomolecules, antimicrobial activity, removal of environmental pollutants, and bioanalytical applications [11]. These nanoparticles are prepared from the metal/metal oxide precursors. Metal/metal oxide nanoparticles include silver, copper, gold, titanium oxide, iron oxide, and zinc oxide [11]. They can be synthesized by chemical, physical, electrochemical, or photochemical approaches. However, due to their negative impact, biological methods have been currently in demand.

2. Biological Approach for Nanocatalyst/Nanoparticle Synthesis

The biological method is preferred over the other two conventional methods (top-down and bottom-up) as it is a green method, environmentally friendly, and does not require a higher energy consumption [18]. Nanoparticles obtained through the biological approach have a greater specific surface area, increase the rate of catalysis, and have metal salt and improved enzymes [19]. Hence, the main objective in the synthesis of nanoparticles using a biological approach is to utilize cheap resources and facilitate a continuous production of nanoparticles. Biological sources that are used for nanoparticle synthesis provide a simple method and easy increase in biomass, ensuring a uniform particle size, as well as multiplication. The use of microbes is one of the most prominent methods among the biological approaches of nanoparticle synthesis. It utilizes different biological sources such as bacteria, fungi, and algae (**Figure 1**). Bacteria are the most commonly found organism in our biosphere. Under optimal conditions such as pH, temperature, and pressure, bacteria show the capability to synthesize various nanoparticles [20] (**Figure 2**). The ability of bacterial cells to survive and proliferate under extreme climatic conditions make them the most ideal organisms for nanoparticle synthesis. They can reproduce and multiply even under high metal concentrations, which may be due to particular resistance mechanisms.

Strains of bacteria that are not resistant to high metal concentrations can also be employed as appropriate microbes. The nanoparticles produced by microorganisms have important uses in the biological field such as bioleaching, biocorrosion, biomineralization, and bioremediation. In addition to bacteria, fungi and algae are two other green sources that are capable of synthesizing nanoparticles. Fungi have an outstanding ability for the synthesis of various bioactive compounds that have potential for numerous applications. They are widely used as reducing and stabilizing agents and can be easily grown on a large scale for the production of nanoparticles with controlled shape and size [21]. Similarly, algae have the ability to synthesize various bioactive compounds, pigments, and proteins, which help in the reduction of salts and act as capping agents in the synthesis mechanism [22].

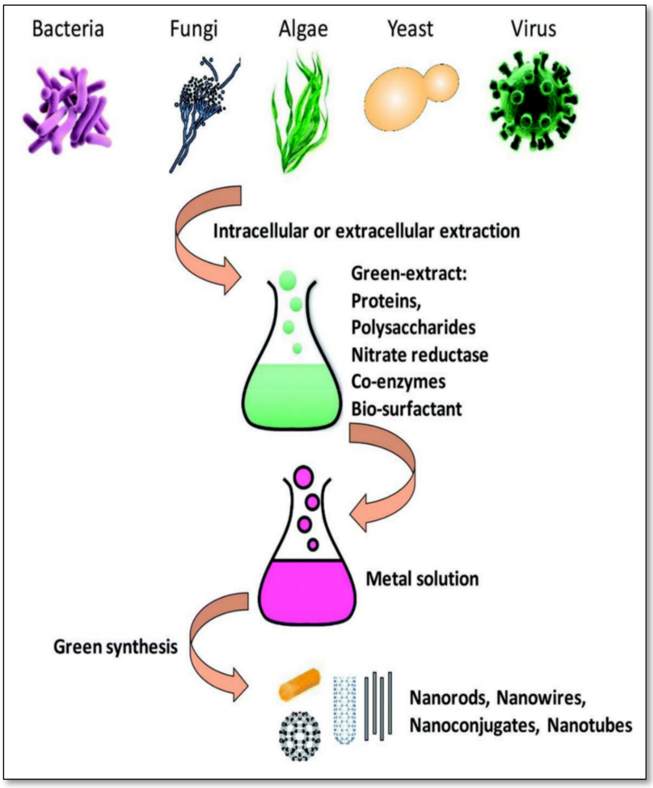

Figure 1. Biological approach to nanoparticle synthesis [22].

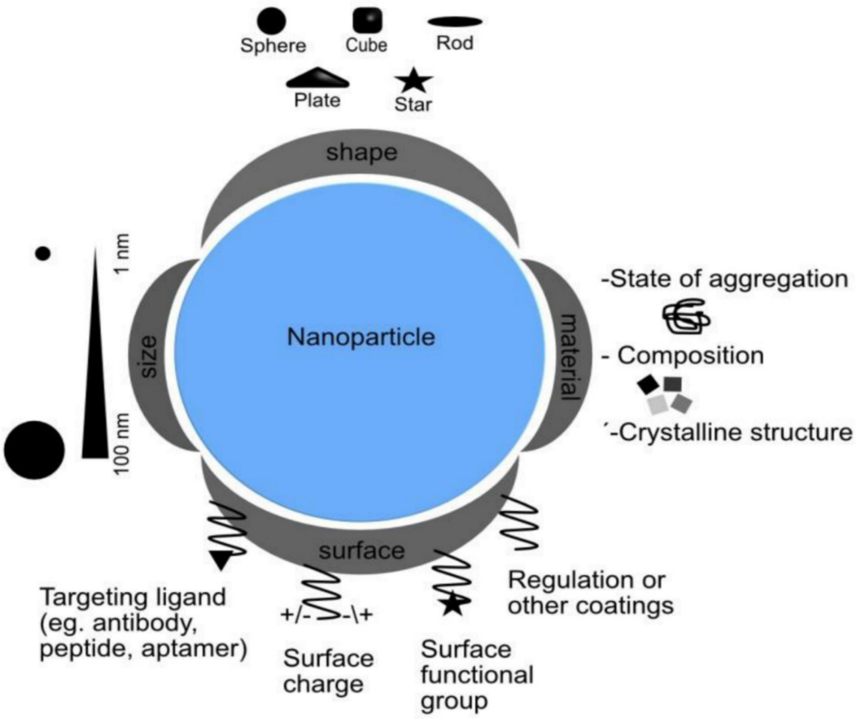

Figure 2. Different physiochemical properties of nanoparticles [20].

3. Conclusions

The development of environmentally friendly and cost-effective techniques for producing nanomaterials and their concomitant applications in various fields is in great demand. Although a range of physical and chemical techniques have been found to be suitable for the synthesis of various nanomaterials, these methods show a nonnegligible concern because of the production of various toxic and nonbiodegradable by products. In this regard, the biogenic synthesis of nanomaterials offers an alternative solution to overcome the existing drawbacks that come from physical and chemical methods. The biological method offers a rigid control on the synthesized particles size and uniform shape, while the physical characteristics are retained at the same level as physical and chemical methods. Biologically synthesized nanomaterials are more prepared for biomedical application because of their lower toxicity. Nanomaterials provide various applications such as dye degradation, heavy metal remediation, and biological activity. However, in biological methods, many parameters affect the synthesis of nanoparticles, including pH, temperature, and whether they are manufactured internally or externally in the cell. These parameters should be studied in order to optimize the synthesis process. It is easy to manipulate bacteria genetically, whereas, in the case of fungi, the downstream process has been shown to be suitable for the large-scale production of nanomaterials. Regardless of the biological sources used, it is crucial to recognize the mechanism behind nanoparticle synthesis for maximum synthesis, which is important for commercialization purposes. Nonpathogenic sources are beneficial for the production of nanoparticles in an effective way. In addition, nanotoxicity should also be considered because it sometimes causes adverse effects on human health and animals. This can be tackled by the implementation of regulation and legislation, and researchers must conduct joint multidisciplinary studies in various fields of medical sciences, nanomedicine, nanotechnology, and biomedical engineering.

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