

MICROBIAL GREEN SYNTHETIC APPROACHES FOR THE PREPARATION OF NANO MATERIALS: AN OVERVIEW

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Abstract

Due of its numerous applications in nearly every field, nanotechnology has garnered a lot of attention and has been developing in the scientific community over the past several years. Green nanotechnology is a relatively new, interdisciplinary discipline that is expanding quickly as a field of study. This is a crucial approach that, in contrast to the already used methods like green and physical methods for nano synthesis, focuses on creating a process that is safe, clean, and especially environmentally friendly. This review summarizes the current understanding of the several biogenic synthesis techniques that rely on viruses, bacteria, fungi, yeast, algae, and biomolecules. The term "green nano synthesis" describes the process of creating nanomaterials by using stabilizing and reducing chemicals derived from plants and other natural resources. The green synthesis method avoids using highly energy-intensive or severely hazardous compounds throughout the synthesis process.

Bio-reducing agents used in nano synthesis might vary, leading to the production of nanoparticles (NPs) with unique sizes, shapes, and bioactivity. Therefore, the information currently available about the biological techniques used to create safer, more ecologically friendly, and environmentally sustainable nano synthesis routes is compiled in this review paper. The primary focus of this review is on the large-scale production of NPs using green synthesis for biomedical and agricultural applications.

1. INTRODUCTION

With so many useful applications, nanomaterials have become a fascinating new class of materials that are much sought after. Five silicon atoms or ten hydrogen atoms lined up, each measuring one nanometer, can be used to illustrate the length of a nanometer. Materials that fall between 1 and 100 nm in size or one of their dimensions are classified as

nanomaterials. It is hard to pinpoint the precise history of human use of nanoscale things. Nonetheless, the usage of nanomaterials is not new; humans have long employed them, albeit unintentionally, for a variety of purposes. About 4500 years ago, humans strengthened ceramic mixtures using asbestos nanofibers [1].

About 4,000 years ago, PbS nanoparticles were known to the ancient Egyptians, who employed them in a traditional hair-dying recipe [2,3]. Another intriguing historical example is the Lycurgus Cup. It's a dichroic cup that the Romans created in the fourth century AD.

In direct light, it has a jade-like appearance; in transmitted light, however, it exhibits a transparent red hue. It changes hue based on the light that is incident onto it. The presence of Ag and Au nanoparticles is the cause of these color changes [4]. In 1914, Richard Adolf Zsigmondy first used the term "nanometer"[5].

In 1959, the American scientist and Nobel Prize winner Richard Feynman gave a speech at the annual meeting of the American Physical Society that established the specific idea of nanotechnology. This is regarded as the first lecture on nanotechnology given by an academic [5]. "There's Plenty of Room at the Bottom" was the title of the lecture he gave. During this conversation, the question "Why can't we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?" was raised.

The goal was to create smaller devices all the way down to the molecular level [6,7]. During this speech, Feynman clarified that working at the atomic and molecular level is not constrained by the rules of nature levels, but rather the thing limiting this is the absence of suitable tools and methods [8]. This sowed the seeds of the idea of contemporary technology. He is frequently regarded as the founder of contemporary nanotechnology as a result. It's plausible that the term "nanotechnology" was first used in 1974 by Norio Taniguchi. According to Taniguchi, "the processing, separation, consolidation, and deformation of materials by one atom or one molecule constitute the main components of nanotechnology [5,9]". Although the concept of nanotechnology was merely a topic of discussion until the 1980s, it had been planted in the minds of researchers with the possibility of further development.

2. Green synthesis of Nano materials

A diverse range of phototrophic eukaryotes, including bacteria, plants, algae, heterotrophic human cell lines, and many biocompatible agents, function as effective and eco-friendly green nano factories. These factories are specifically designed to synthesize

various inorganic nanoparticles. Phototrophic eukaryotes, which are highly stable creatures, have the ability to convert metal ions into metal nanoparticles. Thus, by utilizing this advantage of these phototrophic eukaryotes, microorganisms, plants, and biomolecules could be employed to biologically manufacture the NPs; this process is described in detail in the sections that follow.

2.1 Nano materials using microbiolagents

Many studies have been published recently in light of the increasing interest in creating NPs utilizing biological systems, which is focused on improving various biomimetic designed techniques. Microorganisms employed in biological processes to produce nanoparticles (NPs) are a valuable resource for the synthesis of nanostructured materials, as they are safe, practical from an economic standpoint, and environmentally benign. The selective adsorption of metal ions, the process's ability to operate under a wide range of environmental conditions (such as pH, temperature, and ionic strength), as well as its affordability, ease of availability, rejuvenation, high biosorption capacity, and potential for large-scale acquisition, all contribute to its increased advantages [12-14]. Microorganisms like yeast, fungus, and bacteria have been developed as a novel material for the manufacturing of semiconductors, metal nanoparticles, and quantum dots of various sizes and shapes [14]. These microorganisms are also crucial to the ecology's reprocessing of minerals. The mechanism of metal NPs synthesis is explained in Fig. 1(A). When interacting with the watery form of microorganisms, the metal cations (M^+) of NPs are reduced to metallic form (M^0). By adjusting the synthesizing parameters such as temperature, pH, incubation time, and oxygenation, bio-organisms were able to successfully synthesis metallic nanoparticles (NPs) with varied sizes and forms [12-16]. The methods involved in creating nanoparticles (NPs) using microorganisms are depicted in Fig. 1(B). Enzymes are found in bioresources. Because the metal salts are putting stress on the protein, it will attach to the metal ions. After then, they are converted to nuclei, and NPs begin to grow.

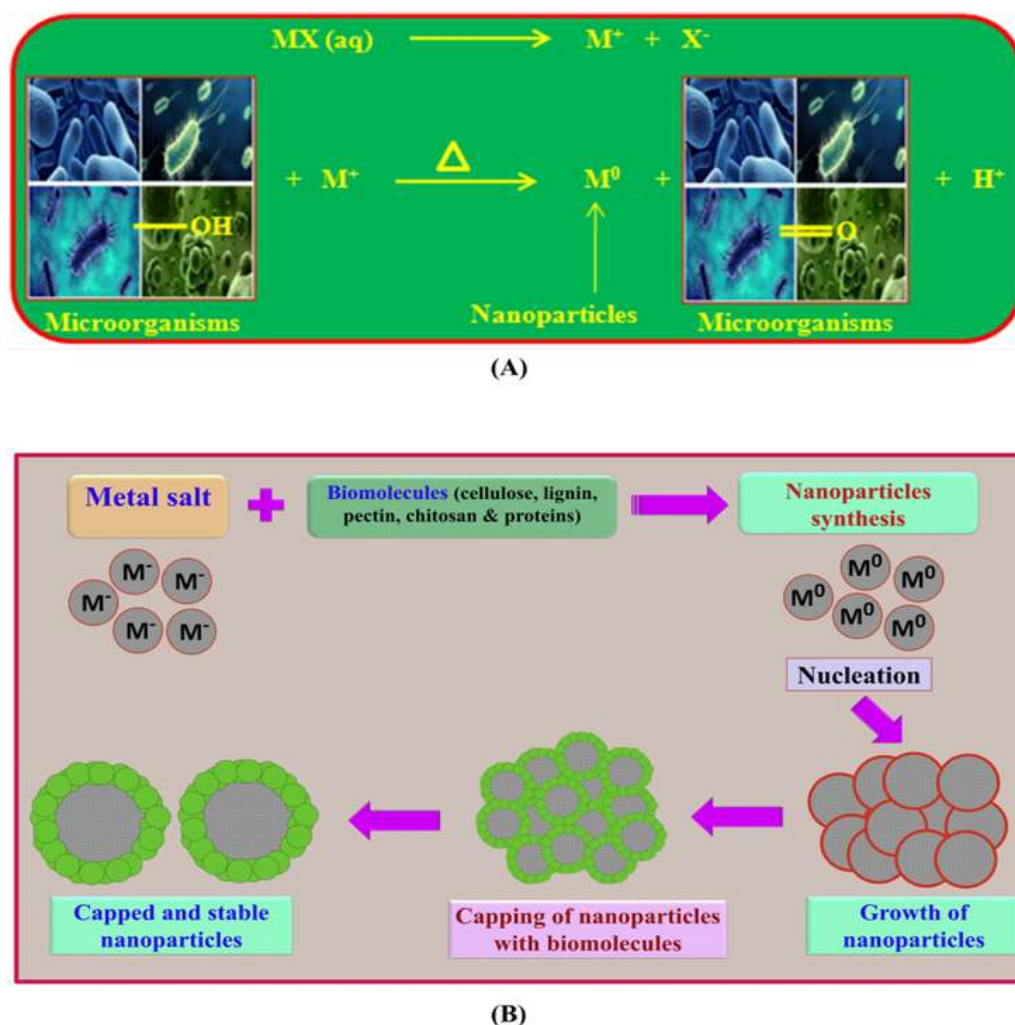


Fig. 1. (A) Mechanism of obtaining NPs using microorganisms. (B) Green synthesis of metallic nanoparticles: mechanisms leading to reduction and stabilization

2.2. Nano materials synthesis by actinomycetes and bacteria

Metal ion reduction into metallic nanoparticles is a skill that bacteria and actinomycetes possess. Numerous investigations have demonstrated that biological microbial systems for nano synthesis may be divided into two groups: extracellular and intracellular ones. In these systems, the formation or synthesis of nanoparticles (NPs) is dependent upon the location of the NPs within the bio reducing system. Because of their many benefits such as low growth costs, rapid growth, and ease of genetic manipulation bacterial systems are a good starting point for the extracellular manufacture of metal nanoparticles. Certain bacteria, including *Escherichia coli*, *Bacillus cereus*, and *Corynebacterium* sp., have been shown to be capable of absorbing and accumulating metal and to be helpful in concurrently lowering environmental pollution. This has led to the establishment of NPs as well as removing metal

from trash. Numerous bacterial strain groups have been thoroughly studied in recent studies, including *Bacillus amyloliquefaciens*, *Acinetobacter calcoaceticus*, *Escherichia coli*, *Bacillus megaterium*, *Pseudo monasstutzeri*, *Bacillus licheniformis*, and *Lactobacillus* sp. These strains have the potential to effectively enhance AgNP synthesis [16]. The antibacterial activities of silver nanoparticles (AgNPs) have been demonstrated against several pathogenic organisms and they were produced through both extracellular and intracellular biogenesis.

Das et al. [6] reported extracellular synthesis of polydispersed AgNPs having an average size about 42–92nm using *Bacillus* sp., which was isolated from soil contaminated by heavy metals in southern India. Metal NPs were reported to have distinctive properties such as surface plasmon resonance (SPR) that prove them as potential candidate for various applications. The AgNPs have UV–vis absorption at 450nm, as has been proven and reported in many studies.

For instance, Konishi et al. [13] have briefly studied *Shewanella* algae, which is a metal-reducing bacterium, for the synthesis of platinum and gold NPs (AuNPs). Another widely used metal NP is gold that has been synthesized intracellularly using alkali tolerant actinomycete (*Rhodococcus* sp.).

Konishi et al. [13] observed that platinum NPs (Pt NPs) (approximately 5nm) and AuNPs (~10–20nm) were stored in the periplasmic space of *S. algae* cells. During the fabrication of AuNPs they have investigated the effect of a pH range of 2.0–7.0, in which they found that in addition to the deposition location, pH plays an indispensable role in the fabrication, size, and morphology of NPs [13].

Bai et al. [17] developed a simple method for cadmium sulfide NPs (CdS NPs) synthesis by photosynthetic bacteria *Rhodospseudomonas palustris* when incubated it with CdSO₄ (1mM) at 30°C for 72h. In this study, they found that cysteine desulfhydrase, which was found in the cytoplasm, is liable for the formation of CdS nanocrystal, and the secreted protein stabilized and formed CdS NPs.

Sweeney et al. [17] described the intracellular synthesis of CdS nanocrystals using *E. coli* when exposed to cadmium chloride and sodium sulfide. The synthesis of 10.5nm PbS NPs was reported using immobilized *Rhodobacter sphaeroides*.

In this study, culture time influences the synthesis of PbS NPs and the extracellular synthesis of NPs by applying advantageous immobilized biomass strategy for large-scale applications [15].

2.3. Nanomaterials synthesis by yeasts

Because of their greater tolerance to hazardous metals, eukaryotic microorganisms like yeasts have been shown in several studies to be suitable for the synthesis of metallic nanoparticles. The synthesis of AgNPs and AuNPs from *Saccharomyces cerevisiae* has been widely investigated. A yeast strain that is resistant to silver, MKY3, demonstrated the capacity to generate extracellular NPs with an average size ranging from 2 to 5 nm [19]. Lately, amine-terminated polyamidoamine dendrimers and cysteine have been used as stabilizers to reduce the gold salt and create AuNPs utilizing the yeast species *Hansenula anomala*.

The produced nanoparticles shown antibacterial activity against *Pseudomonas putida* and *Bacillus cereus*. *Yarrowia lipolytica* NCIM3589 was used in the biosynthesis of AuNPs, which was investigated and revealed that NPs were deposited in the yeast cell wall. A few studies have reported the intracellular production of persistent lead sulfide nanoparticles (NPs) by the marine yeast *Rhodospiridium rubroovatum*, and mushroom species have also been investigated for the production of green NPs.

Lin et al. (2005) [20] investigated that the baker's yeast *S. cerevisiae* showed the ability to biosorb and reduce Au^+ to elemental Au^0 in the cell wall (peptidoglycan layer) in situ because of presence of the aldehyde group in reducing sugars.

Pichia pastoris was investigated for the intracellular synthesis of AuNPs, which led to different morphologies of AuNPs within 24h [21].

A comparative study of the synthesis of manganese dioxide NPs (MnO_2 NPs) from KMnO_4 by marine bacterium *Saccharophagus degradans* and the yeast *S. cerevisiae* showed the importance of the medium and medium constituents in positive reactions. The washed *S. degradans* showed ability to produce MnO_2 NPs, while the medium and medium components displayed comparable positive reactions. The importance of this study is that it showed how microorganisms without any ability to synthesize NPs can also be reported as returning positive results [22].

Recently, *S. cerevisiae* was also utilized for synthesizing cadmium telluride quantum dots possessing systemic biocompatibility and thus could be useful in the fields of bioimaging and bio labelling. *Schizosaccharomyces pombe* yeast cells showed the ability to synthesize wurtzite-type hexagonal lattice-structured CdS quantum dots intracellularly and exhibit ideal diode characteristics [19]

2.4. Nanomaterials synthesis by fungi

Due to their special qualities such as their resistance to toxicity, ease of handling and process scaling, large surface areas that result in increased production rates, simple and easy downstream processing, economic viability, and the larger spectrum of NPs morphologies and intracellular metal uptake capabilities compared to bacterial systems—fungi could be regarded as an ideal candidate and extensively studied for the synthesis of metallic NPs. To create AgNPs, fungi including *Trichoderma* sp., *Fusarium oxysporum*, and *Cochliobolus lunatus* have been used [21].

Fungi such as *Cochliobolus lunatus*, *Fusarium oxysporum*, and *Trichoderma* sp. have been exploited for the synthesis of AgNPs. The extracellular biosynthesis of AgNPs using *Aspergillus fumigates* and *A. clavatus* has been also extensively studied [25].

The biosynthesis of AgNPs using *Pleurotus* and *Phoma* sp. and an industrial edible mushroom *Volvariella volvacea* has been reported [23].

Verticillium sp., *Penicillium* sp., and *Hormoconisresinae* proved great ability of fungal sources for the extracellular synthesis of AuNPs with considerable stability in the solution [26].

The filamentous non-pathogenic fungus *Neurosporacrassa* was able to successfully generate mono- and bimetallic Au/Ag NPs [27].

Dead mass of the filamentous fungi *Hypocrealixii* was used to uptake copper from the waste water and as a biological agent to synthesize Cu NPs. The average size was 24.5nm and the Cu NPs were located inside the cell wall of *H. lixii* [29].

2.5. Nanomaterials synthesis by viruses

Given their potent capacity to bind into necessary structures with a variety of morphologies, virus-based nanocomposites are crucial bioengineering materials for creating intelligent nano-objects. Due to their ability to disperse in a monolayer, their stable and robust NP synthesis, and the ease with which viral plat can be genetically manipulated for mscan, viruses exhibit unique characteristics that make them an ideal template for the synthesis of nano-conjugates with noble metal NPs. Because of their distinct architectures, viruses can be thought of as natural nanostructures and may serve as a model for the production of various NP morphologies and sizes. They are useful for the regulated synthesis of monodispersed NPs due to their uniform size, clearly defined architectures, and the presence of different surface functional groups, viruses, and their protein cages.

Yang et al. [30] was able to use the Tobacco Mosaic Virus (TMV) for the spontaneous synthesis of highly crystalline, uniform and ultrafine (1–2 nm) palladium NPs without any further reducing agent. They also showed the importance of the precursor concentration and TMV for the formation of homogeneous Pd NPs [31].

Titanium dioxide is a widely used nanomaterial in the field of electronics; Chen et al. [89] used M13, which is a filamentous bacteriophage that infects *E. coli*, to synthesize titanium dioxide nanowires for a tunable semiconductor mesoporous network. The titanium precursor was initially incubated with virus particles at extremely low temperature (−40°C), during which the titanium ion complexes bound electrostatically with the virus negatively charged acidic group.

In a separate study, genetically engineered M13 was used in the fabrication of photocatalytically active perovskite strontium titanate (SrTiO₃) nanowires. The biotemplated SrTiO₃ was then doped with nitrogen using ammonia to obtain a photocatalytically active nanomaterial [32].

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