Trends in Biotechnology

CellPress

Review

Biological Synthesis of Nanoparticles from Plants and Microorganisms

Priyanka Singh,[1] Yu-Jin Kim,[1,2,*] Dabing Zhang,[2] and Deok-Chun Yang[1,*]

Nanotechnology has become one of the most promising technologies applied in all areas of science. Metal nanoparticles produced by nanotechnology have received global attention due to their extensive applications in the biomedical and physiochemical fields. Recently, synthesizing metal nanoparticles using microorganisms and plants has been extensively studied and has been recognized as a green and efficient way for further exploiting microorganisms as convenient nanofactories. Here, we explore and detail the potential uses of various biological sources for nanoparticle synthesis and the application of those nanoparticles. Furthermore, we highlight recent milestones achieved for the biogenic synthesis of nanoparticles by controlling critical parameters, including the choice of biological source, incubation period, pH, and temperature.

Trends

The biological synthesis of nanoparticles is increasingly regarded as a rapid, ecofriendly, and easily scaled-up technology.

Metal nanoparticles produced using microorganisms and plant extracts are stable and can be monodispersed by controlling synthetic parameters, such as pH, temperature, incubation period, and mixing ratio.

Recently, biological nanoparticles were found to be more pharmacologically active than physicochemically synthesized nanoparticles.

Among the various biological nanoparticles, those produced by medicinal plants have been found to be the most pharmacologically active, possibly due to the attachment of several pharmacologically active residues.

Nanoparticles and their Applications

Nanotechnology (see Glossary) has become one of the most important technologies in all areas of science. It relies on the synthesis and modulation of **nanoparticles**, which requires significant modifications of the properties of metals [1]. Nanomaterials have in fact been used unknowingly for thousands of years; for example, gold nanoparticles that were used to stain drinking glasses also cured certain diseases. Scientists have been progressively able to observe the shape- and size-dependent physiochemical properties of nanoparticles by using advanced techniques. Recently, the diverse applications of metal nanoparticles have been explored in biomedical, agricultural, environmental, and physiochemical areas (Figure 1) [1–5]. For instance, gold nanoparticles have been applied for the specific delivery of drugs, such as paclitaxel, methotrexate, and doxorubicin [2]. Gold nanoparticles have been also used for tumor detection, angiogenesis, genetic disease and genetic disorder diagnosis, photoimaging, and **photothermal therapy.** Iron oxide nanoparticles have been applied for cancer therapy, hyperthermia, drug delivery, tissue repair, cell labeling, targeting and immunoassays, detoxification of biological fluids, magnetic resonance imaging, and **magnetically responsive drug delivery** therapy [6–8]. Silver nanoparticles have been used for many antimicrobial purposes, as well as in anticancer, anti-inflammatory, and wound treatment applications [9]. Due to their biocompatible, nontoxic, self-cleansing, skin-compatible, antimicrobial, and dermatological behaviors, zinc and titanium nanoparticles have been used in biomedical, cosmetic, ultraviolet (UV)-blocking agents, and various cutting-edge processing applications [10,11]. Copper and palladium nanoparticles have been applied in batteries, polymers, plastics plasmonic wave guides, and optical limiting devices [12,13]. Moreover, they were found to be antimicrobial in nature against many pathogenic microorganisms. Additionally, metal nanoparticles have been used in the spatial analysis of various biomolecules, including several metabolites, peptides, nucleic acids, lipids, fatty acids,

[1]Department of Oriental Medicine Biotechnology, College of Life Science, Kyung Hee University, Yongin 446-701, Korea
[2]Joint International Research Laboratory of Metabolic & Developmental Sciences, Shanghai Jiao Tong University–University of Adelaide Joint Centre for Agriculture and Health, State Key Laboratory of Hybrid Rice, School of Life Sciences and Biotechnology, Shanghai Jiao Tong University, Shanghai, China

*Correspondence: yujinkim@khu.ac.kr (Y.-J. Kim) and dcyang@khu.ac.kr (D.-C. Yang).

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glycosphingolipids, and drug molecules, to visualize these molecules with higher sensitivity and spatial resolution [14].

In addition, the unique properties of nanoparticles make them well suited for designing electrochemical sensors and biosensors [15]. For example, nanosensors have been developed for the detection of algal toxins, mycobacteria, and mercury present in drinking water [16]. Researchers also developed nanosensors by utilizing nanomaterials for hormonal regulation and for detecting crop pests, viruses, soil nutrient levels, and stress factors. For instance, nanosensors for sensing auxin and oxygen distribution have been developed [17].

To date, due to the physiochemical properties and many applications of nanoparticles, the scientific community has dedicated extensive efforts to develop suitable synthetic techniques for producing nanoparticles. However, various physiochemical approaches for the synthesis of metal nanoparticles are limited by the environmental pollution caused by heavy metals. Thus, synthesizing nanoparticles by biological means, which has the advantages of nontoxicity, reproducibility in production, easy scaling-up, and well-defined morphology, has become a new trend in nanoparticle production. In particular, microorganisms and plants have been demonstrated as new resources with considerable potential for synthesizing nanoparticles. To date, several microorganisms, including bacteria, fungi, and yeast, as well as plants, have been explored for the synthesis of metal nanoparticles. While the synthesis of nanoparticles has been extensively reviewed elsewhere [5,18–20], here we provide an update on recent advances in the synthesis of **biological nanoparticles**, and describe prospects for their future development and applications.

Nanoparticle Synthesis Using Microorganisms

Microorganisms have been shown to be important nanofactories that hold immense potential as ecofriendly and cost-effective tools, avoiding toxic, harsh chemicals and the high energy demand required for physiochemical synthesis. Microorganisms have the ability to accumulate and detoxify heavy metals due to various reductase enzymes, which are able to reduce metal salts to metal nanoparticles with a narrow size distribution and, therefore, less polydispersity. The mechanism and experimental methods of synthesizing nanoparticles in microorganisms is described in Box 1. Over the past few years, microorganisms, including bacteria (such as actinomycetes), fungi, and yeasts, have been studied extra- and intracellularly for the synthesis of metal nanoparticles (Table 1). An array of biological protocols for nanoparticle synthesis has been reported using bacterial biomass, supernatant, and derived components. Among the various methodologies, extracellular synthesis has received much attention because it eliminates the downstream processing steps required for the recovery of nanoparticles in intracellular methodologies, including sonication to break down the cell wall, several centrifugation and washing steps required for nanoparticle purification, and others. Moreover, metal-resistant genes, proteins, peptides, enzymes, reducing cofactors, and organic materials have significant roles by acting as reducing agents. Furthermore, these help in providing natural capping to synthesize nanoparticles, thereby preventing the aggregation of nanoparticles and helping them to remain stable for a long time, thus providing additional stability.

In recent research, bacteria, including *Pseudomonas deceptionensis* [21], *Weissella oryzae* [22], *Bacillus methylotrophicus* [23], *Brevibacterium frigoritolerans* [24], and *Bhargavaea indica* [25,26], have been explored for silver and gold nanoparticle synthesis. Similar potential for producing nanoparticles has been showed by using several *Bacillus* and other species, including *Bacillus licheniformis*, *Bacillus amyloliquefaciens*, *Rhodobacter sphaeroides* [27–29], *Listeria monocytogenes*, *Bacillus subtilis*, and *Streptomyces anulatus* [29,30]. Various genera of microorganisms have been reported for metal nanoparticle synthesis, including *Bacillus, Pseudomonas, Klebsiella, Escherichia, Enterobacter, Aeromonas*, *Corynebacterium, Lactobacillus,*

Glossary

Biocompatibility: the compatibility and noninjurious effects of metal nanoparticles within the human body or healthy living cells.
Biological nanofactories: biological sources capable of synthesizing metal nanoparticles, including microorganisms and plants.
Biological nanoparticles: nanoparticles obtaintend form biological sources, such as micoroganisms and plant extracts.
Biological synthesis: synthesis using natural sources, avoiding any toxic chemicals and hazardous by-products, usually with lower energy consumption.
Magnetically responsive drug delivery: delivery of heavy drugs by magnetic nanoparticles under the influence of an external magnetic field.
Mycosynthesis: biological synthesis of metal nanoparticles from fungi.
Nanoparticles: small particles with all three dimensions measuring <1000 nm.
Nanotechnology: technology dealing with the development and application of nanoparticles.
Photothermal therapy: therapy in specific cells, such as cancer cells, by gold or iron nanoparticles under the influence of an external thermal field.
Phytonanotechnology: the biological synthesis of metal nanoparticles from plant resources, which further includes the optimization and applications of synthesized nanoparticles.