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A review on biogenic synthesis of gold nanoparticles, characterization, and its applications

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ABSTRACT

The nano-sized particles make an imprint on us in our daily lives and it has great importance in the numerous fields of biotechnology like the food industry, medical and industrial field. Gold nanoparticles are one of the widely used particles as it has many therapeutic applications, such as drug delivery system for many diseases like cancer, cardiovascular diseases, diabetes mellitus etc. biosensors, and environmental applications of dye degradation, bioremediation of toxic chemicals present in the environment (soil and atmosphere). Gold nanoparticles synthesis by the green route has become the latest development, because of the bioavailability of sources like plants or microorganisms, and it also reduces the utilization of toxic chemicals. This review explains the various microorganisms like bacteria, algae, fungi, actinomycetes and yeast involved in the synthesis of these nanoparticles also elucidate the size, shape and functional groups involved in the synthesis of nanoparticles and its applications.

Introduction

Nanotechnology, a combination of principles involving biology, physical and chemical that creates nano-sized particles holding particular functions [1–4]. For this purpose, noble metal nanoparticles like silver, gold, platinum, palladium etc. and non-metallic, inorganic oxides like the zinc oxide, titanium oxide have been widely exploited because of their unique electronic, mechanical, optical, chemical and magnetic properties [5–10]. The nanoparticles have unique properties of exhibiting larger surface area to volume ratio, size, shape like spherical or rod, etc. due to which they are being used in the various fields of diagnostic biological probes, optoelectronics, display instruments, catalysis, fabricating biological sensors, diagnosis or monitoring diseases like cancer cells, drug discovery, detecting environmental toxic metals or reagents and in therapeutic applications [11–15]. For the synthesis of nanoparticles, there has been an increase in the development of healthy and environment-friendly methods which don't require the exploitation of the toxic chemicals. The growth of metal nanoparticles using physical or chemical methods are not gracious or healthy owing to the use of reducing agents which are highly reactive or toxic in nature for human consumption or to the environment, and these are also quite expensive for upscale production. The green synthesis involves microbes as reducing agents like fungi, bacteria, algae, virus and plants amongst which algae, is known as the "bio-nano factories" as it is environmentally effective, affordable, are uniquely structured, macroscopic and have a high capability of metal uptake [13–17]. The toxic chemicals produced during the nanoparticle synthesis can easily be degraded with the help of enzymes present in the microbes or plants. For example, in the case of fungi, the nitrate reductase is involved in the nanoparticle reduction [18,19].

The reduction of Au (III) ion to Au atom involves binding of the atom to the cell surface, while other reduced Au also binds and aggregates to form gold nanoparticles. When it comes to bulk, gold (Au) is considered to be an inert or non-reactive metal for many chemical reactions, but when gold is synthesized in nano-sized particles, they have many unique properties, like the localized surface plasmon resonance (LSPR), the electronic properties like electronic motion with spatial length scale also decreases with size, the change in individual localized levels of energy and the novel unique properties with the quantum size effects have drastic chemical changes in the transition from bulk to nano size particles [20,21]. As shown in the Fig. 1, the gold nanoparticles with different shapes produced by diverse microorganisms perform numerous functions which are associated in many fields of applications like medicine, diagnosis and therapy or cancer treatment, as anti-angiogenesis, anti -arthritic, antimalarial agents and so on. Nanocomposites of Ag- graphene, Au-graphene or Au-SnO_2 are developed on the electrochemically active biofilms (EABs), which

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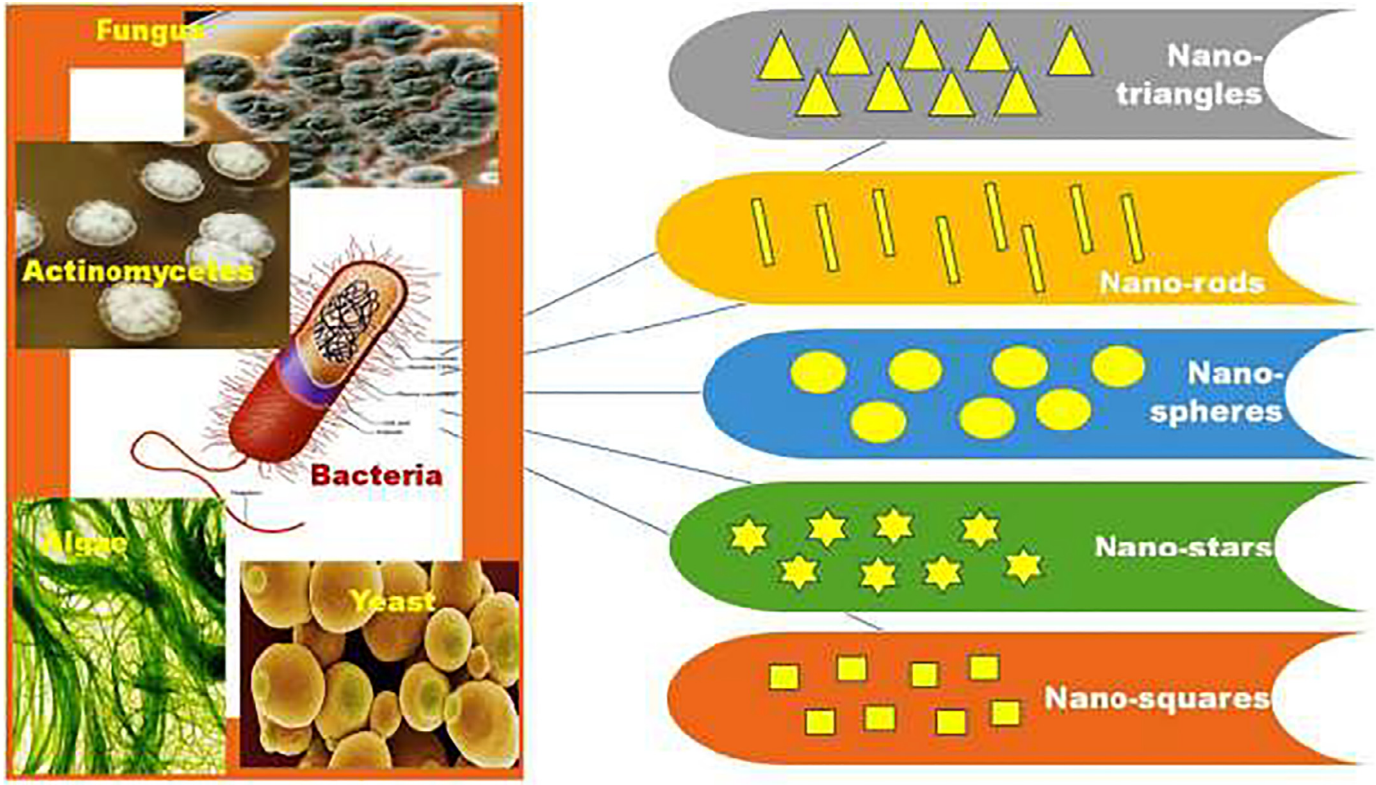

Fig. 1. The gold nanoparticle with different shapes produced from various microbial sources.

helps in the bio-reduction of the gold nanoparticles and doesn't require the use capping or surfactants for the reduction. These nanocomposites are used in various applications of sensors, photoelectrodes, optoelectronic devices, photocatalysis, photovoltaic, ultracapacitors and also photovoltaic because of their excellent photoelectrochemical and photocatalytic properties that it possesses [22–25].

Microbial synthesis of nanoparticles

Microbes have been used for the synthesis of nanoparticles due to their ease of handling, growing in a low-cost medium like cellulosic wastes or wastelands, maintaining the safety levels, having the potential of adsorbing the metal ions and reducing them into nanoparticles by the enzymes produced by metabolic processes [26,27].

The nanoparticle synthesis by microbes can be intracellular or extracellular depending upon the location. The intracellular mechanism is the transportation of specific ions into the cell wall, which is negatively charged, and with the positive charged metals they get diffused through cell wall by electrostatic attraction. Then, the enzymes present in the cell walls of the microbes convert the toxic metals into no- toxic metal nanoparticles. While, the extracellular mechanism involves enzyme mediated synthesis like nitrate reductase or hydroquinone synthesized by many fungi or prokaryotic organisms, converting the metallic ions to metallic nanoparticles. A similar mechanism was found out for gold nanoparticles synthesized from *Rhodomonas capsulate* [28,29]. The detoxification mechanisms employed by the microorganisms includes vacuole compartmentalization, metal binding or volatilization i.e. converting metals into volatile states.

When the microbes are under metal-stress situations, for survival they perform various mechanism to eliminate the heavy toxic metals. It involves an active efflux of metallic ions through the cell membranes, reduction of toxic metals ions to non- toxic ions, and also accumulating the metal ions within the cells. The heavy metal like gold, silver, lead, nickel and etc. influx is mediated through ion pumps, carrier mediated transport, endocytosis, ion channels or lipid permeation [30]. Chelating agents like siderophores are small ion binding molecules that chelate heavy metals, mediate absorption and helps in transportation from the cell of the microbes [31]. Molecules like glutathione which are derived peptides (phytochelatin) binding metals [32] or Metallothioneines (MTs), a cystien – rich protein, low molecular weight which are isolated from *Syneococcus sp., Pseudomonas putida, Cyanobacterium* and *E. coli*, perform primary function of metal detoxification [33].

Synthesis by bacterial strains

The Fe(III)-reducing bacteria like *Geobacter sp. Magnetospirillum magnetotacticum,* and so on can be used for bio-remediation of toxic metals like Fe (III) through reduction, where iron is actively taken by the cell, re-oxidized to hydrous oxide (low density) to Fe(III) oxide (ferrihydrite), which is of high density. The Fe(III) ions in the last step is reduced and magnetite is produced from dehydration within the magnetosome vesicles. An intracellular protein Ferritin, accumulates the iron within the vesicles keeping it in non-toxic and soluble form. The nanoparticles produced have following characteristics like high purity, little crystalline defects, narrow size, mono-dispersive and so on [29]. The thermophilic bacteria can be an excellent tool for the extracellular synthesis of both gold and silver nanoparticles. These extracellular systems produce an environment-friendly alternative for huge quantities of nanomaterials reducing the downstream processing of these metals [33]. The MDR (multi-drug resistance) bacteria have developed antibacterial agents that act against gram positive or negative bacteria. A known fact, that gram negative has a very thin peptidoglycan layer of cell wall which is susceptible to the action of nanoparticles