REVIEW OF GREEN METHODS OF SYNTHESIS OF SILVER NANOPARTICLES

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Green synthesis of metal nanoparticles is a very promising area of research. Silver nanoparticles are the most interesting type of nanoparticle in nanotechnology because they have varied properties, such as antibacterial, antioxidant, and antibiofilm forming properties. This review aims to establish which of the most common approaches for the biological synthesis of nanoparticles is the best. In this work, the methods of synthesis of silver nanoparticles using plant extracts, bacteria, and yeast are considered. Each of these methods has its advantages and disadvantages. The most common method of synthesis of silver nanoparticles is the method using plant extracts, however, stabilizing substances from plant extracts have their own direct biological activity, which can be both enhanced and suppressed by silver nanoparticles. Green synthesis of nanoparticles thanks to microorganisms makes it possible to use a wide range of bacterial strains, but it is important to remember of the pathogenicity of the strains and their danger to humans. From this perspective, the use of yeast for the synthesis of silver nanoparticles is the most promising method, as it allows obtaining a large amount of nanomaterial. The synthesis, thanks to yeast method, allows us to control the size and shape of the nanoparticles. Nanoparticles obtained from yeast lysates have effective antibacterial and antifilm-forming activity.

Keywords: silver nanoparticles, green synthesis, biotechnology

INTRODUCTION

At the nanoscale, there are significant differences in many material properties that are not usually observed in the same materials at the macroscale. Physical and chemical methods of nanoparticle synthesis have certain disadvantages due to their environmental hazards and high-energy costs. The biological method of synthesis is an environmentally friendly technology that involves the use of biological materials, such as actinomycete algae, bacteria, fungi, viruses, yeasts and plants, to create nanoparticles through transformations in a number of biochemical and biophysical processes. Biological synthesis using nanobiotechnological processes has significant potential to increase the production of nanoparticles without the use of aggressive, toxic and expensive chemicals as mentioned by Shah *et al*. (2015). Among nanoparticles, special attention is paid to silver nanoparticles due to their antimicrobial activity, the possibility of use as drug delivery agents, use as a nanocoating for medical equipment, etc. (Velusamy *et al*., 2016).

Numerous biological materials are used for the intracellular and extracellular biosynthesis of nanoparticles: bacteria, fungi, yeast, algae, actinomycetes, and plant extracts. Green synthesis makes it possible to obtain nanoparticles of variable size, shape, and degree of stability, which have defined mechanical, optical, magnetic and chemical properties related to their shape, size, surface charge and surface area (Salem and Fouda, 2021).

In this review, the authors conduct a brief analysis of the spectrum of materials used for the green synthesis of silver nanoparticles.

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SYNTHESIS OF SILVER NANOPARTICLES USING PLANT EXTRACTS

Jagtap and Bapat (2013), Arokiyaraj *et al*. (2015), Mittal *et al*. (2013) and Kazlagić *et al*. (2020) report the synthesis of Ag nanoparticles using plants, in particular, using extracts of *Artocarpus heterophyllus*, *Chrysanthemum indicum*, *Polyalthia longifolia*, *Cinnamomum camphora*, *Ficus benghalensis*, *Pelargonium graveolens*, *Datura metel*, *Eclipta prostrata*, *Piper longum*, *Malus domestica*. Furthermore, the authors report on the antifungal and antibacterial properties of nanoparticles obtained from plant extracts, in particular against *Candida albicans*, *Escherichia coli*, *Salmonella* spp., *Bacillus cereus*, *Bacillus subtilis*, *Staphyloccocus aureus*, *Pseudomonas aeruginosa*. To analyze the characteristics of nanoparticles obtained thanks to plant extracts, generally accepted methods of analysis are used. Thus, for nanoparticles obtained by synthesis using a plant extract from the leaves of *Mentha arvensis*, the absorption peaks of reduced silver at 1650 cm^{-1} were shown using IR-Fourier transform spectroscopy, and the absorption peak in the region of 340 nm was determined using UV spectroscopy. The obtained nanoparticles demonstrate a maximum activity of 40% observed at a concentration of 600 µg/ml (SivaKumar *et al*., 2015).

The main mechanism for the formation of Ag nanoparticles is based on reactions involving phytochemicals such as terpenoids, flavonoids, ketones, aldehydes, amines, and carboxylic acids. Flavones, organic acids and quinones participate in the immediate reduction of Ag^{+} ions (Abou El-Nour *et al*., 2010).

Plant extracts are a good material for the synthesis of silver nanoparticles. However, the stabilizing substances in the extracts themselves have biological properties. Nanoparticles stabilized by substances from plant extracts can either enhance the effect of flavonoids, amines, aldehydes, etc., or reduce it. Moreover, certain substances can be toxic to normal cells of the human body.

MICROORGANISMS FOR THE SYNTHESIS OF SILVER NANOPARTICLES

Bacteria synthesize nanoparticles both intracellularly and extracellularly. An example of intracellular production of nanoparticles is the synthesis of Ag nanoparticles thanks to bacteria *Rhodococcus* sp. — the accumulation of nanoparticles occurs in the cytoplasm (Otari *et al*., 2015). Moreover, *Vibrio alginolyticus* is used, which synthesizes Ag nanoparticles by reducing silver nitrate (Rajeshkumar *et al*., 2012), and the bacterium *Pseudomonas stutzeri* AG 259, isolated from silver mines, produces nanoparticles inside the periplasmic space of the bacterium (Prabhu and Poulose, 2012). Seetharaman *et al*. (2018) used *Phomopsis liquidambaris* to synthesize Ag nanoparticles. They obtained nanoparticles with a spherical shape and an average size of 18.7 nm, which had antimicrobial and anti-mosquito activity.

The exact mechanism of nanoparticle production by bacteria has not yet been elucidated. However, it is known that during the synthesis of metal nanoparticles intracellularly or extracellularly, it is necessary to consider important physicochemical parameters such as pH, contact time, temperature, the number of bacteria and the concentration of metal salts (Beveridge and Murray, 1980). An interesting fact is that the accumulation of metal ions in the cell is one of the mechanisms of resistance to silver in microorganisms. It is possible that the phenomenon of biosynthesis of silver-based single crystals is based on this. Thus, thanks to *Pseudomonas stutzeri* AG259, nanoparticles with a well-defined shape, such as equilateral triangles and hexagons up to 200 nm in size, are

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synthesized at the cell poles. These Ag-containing crystals are embedded in the organic matrix of the bacteria (Klaus, 1999).

The use of bacteria as material for the synthesis of silver nanoparticles is limited by the direct antibacterial effect of silver. Furthermore, the safety of using silver nanoparticles synthesized by bacteria is limited to pathogenic strains. This method has prospects under the condition of using bacteria useful for the human body, for example, lactic acid and probiotic strains.

YEAST AS AN OBJECT OF THE SYNTHESIS OF SILVER NANOPARTICLES

Yeasts are potentially the best biological agents for the synthesis of nanoparticles due to the use of simple and controlled environments, rapid biomass growth (Sasidharan and Joseph, 2014).

There are various approaches to the synthesis of nanoparticles using yeast as biomatrices. In particular, lyophilized yeast and live cultures can be used for synthesis. Thus, when using *Saccharomyces cerevisiae*, it was found that when using freshly cultivated cells, the yield of nanoparticles is greater than when using a lyophilized preparation. The resulting Ag nanoparticles are spherical with a diameter of 2-20 nm. In yeast cells, nanoparticles accumulate inside the cell membrane, or are attached to the cell membrane during exocytosis. A certain number of nanoparticles is synthesized extracellularly (Korbekandi *et al*., 2016).

For the synthesis of Ag nanoparticles, it is possible to use supernatants of yeast cultures, in particular, such as *Cryptococcus laurentii* and *Rhodotorula glutinis*. These nitrate-reducing yeasts made it possible to obtain dispersed and stable nanoparticles that had differences in size, zeta potential, concentration, and stabilizing compounds depending on the type of yeast (Fernández *et al*., 2016).

Furthermore, for the synthesis of Ag nanoparticles, yeast extract can be used as a source of reducing and capping agents. Ag nanoparticles thus synthesized have a uniform spherical shape with an average size of 13.8 nm. A significant role in the formation of such Ag nanoparticles is played by biomolecules of reducing amino acids, alpha-linolenic acid and carbohydrates found in the yeast extract (Shu *et al*., 2020).

Synthesis of nanoparticles using yeast is the safest method. In addition, the size and shape of silver nanoparticles can be adjusted with this method.

CONCLUSIONS

Silver nanoparticles obtained by green synthesis have various biological properties, namely antioxidant, antibacterial and antifungal properties. The variety of approaches to "green" synthesis using yeast provides significant potential for regulating the shape, size, and composition of reducing and capping agents, which in turn determines the biological properties of synthesized silver nanoparticles.

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