Review Article

A Review of the Application of Nanoparticles Biosynthesized by Microalgae and Cyanobacteria in Medical and Veterinary Sciences

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ABSTRACT

Green synthesis of nanoparticles is an environmentally friendly method to produce nanoparticles with unique biological, physical, and chemical properties. Today, biological synthesis methods have drawn significant attention because of the drawbacks of physical and chemical synthesis, such as poisonous side effects, time and power usage, and heavy price. Among different microorganisms, cyanobacteria are suitable candidates as regenerating and stabilizing agents because of their capability to collect heavy metals from the environment and produce various bioactive compounds such as colorants and enzymes. The green synthesis of nanoparticles by cyanobacteria has captivated extensive consideration as a secure, easy, stable, economical, and environmentally friendly resolution for biomedical and veterinary applications. Meanwhile, the secondary metabolites synthesized by cyanobacteria with the ability of extracellular and extracellular metals reduction and oxidation are very noteworthy and have antibacterial, antifungal, anti-algae, anticancer, and photocatalytic activities. This study considers the properties, as well as biomedical and veterinary applications of nanoparticles generated by cyanobacteria.

Keywords: Biomedical and veterinary applications, Cyanobacteria, Green synthesis, Microalgae, Nanoparticles

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1. Introduction

In recent decades, nanotechnology has greatly advanced because of the exceptional physical and chemical characteristics of nanoparticles. Nowadays, it has spread to about all scientific fields to create new alternatives and to solve bottlenecks related to various types of research topics. The basis of nano-biotechnology is the creation of nanoparticles with the help of biological organisms, which may affect the physical properties of nanoparticles (Zinicovscaia et al., 2016).

Nanoparticles are produced in various sizes and shapes because of their new properties compared to their bulk peers. The chemical, biochemical, and physicochemical characteristics of nanoscale substances are very different, mainly because of the high surface-to-volume ratio, which causes significant differences in their mechanical qualities, melting point, light absorption, thermal conductivity, biological, and catalytic activities (Mandhata et al., 2022). Nanoparticles act as a bridge between bulk matter and atomic or molecular structures. Ordinarily, they are 1 to 100 nm in size and classified based on their structural configuration, origin, and dimensions. Because of the incomparable morphological and physicochemical properties (form, charge distribution, and size) of nanoparticles, they are used in almost all scientific fields, such as space, power, defense, communication, biomedicine, veterinary, and farming (Nowruzi et al., 2020). Nanoparticles are also used to diagnose and treat diseases, deliver drugs, and imaging in tissue engineering. However, nanoparticle usage in biological organisms, especially humans, is crucial, and nanoparticles for biomedical and veterinary applications should be supplied from environmentally reliable sources (Yalcin et al., 2022).

Classification of Nanoparticles

Nanoparticles may be classified based on different factors, such as form and size, phase composition, quiddity, and creation. For example, organic nanoparticles are found in the biosphere due to the development of heavy metals in living organisms, as well as those that occur randomly from forest fires, volcanic eruptions, rock weathering, clay mineral explosions, soil erosion, and hurricanes. High sand, conversely, is engineered nanoparticles generated through chemical and physical pathways (San Keskin et al., 2016). Also, nanoparticles can be classified based on their chemical content. Mineral nanoparticles contain metallic oxides and nanoparticles like gold, titanium oxide, zinc oxide, silver, platinum, copper oxide, and iron oxide nanoparticles, while natural nanoparticles contain chitosan and carbon nanoparticles (Hamida et al., 2020).

Nanoparticles synthesis and properties

There are many ways to synthesize nanoparticles, involving traditional techniques like physical and chemical approaches, as well as contemporary methods like biological synthesis using vitamins, natural living organisms, and enzymes (Bin-Meferiji & Hamida, 2019; Ghasemipour et al., 2017). In chemical reactions, atoms move to nuclei to produce nanoparticles. In the chemical procedure, the principal constituents are reducing agents, the forerunner, and establishing metals. Regenerative agents contain ascorbate, sodium borohydride, and sodium citrate. Stabilizers contain sodium carboxyl, starch, methylcellulose, and polyvinyl pyrrolidone. Nanoparticles are mainly made through chemical and physical processes like electron and cell explosion or mechanical grinding. These methods are dangerous for the environment and human health. Nanoparticles green synthesis is an environmentally safe, affordable, and non-toxic alternative. Organisms like plants, fungi, bacteria, and algae contribute to the green synthesis of pure nanoparticles (Velusamy et al., 2016; Nowruzi et al., 2021).

These biological systems act as both regenerative and inhibitory agents in the production of nanoparticles either intracellularly or extracellularly. Functional groups (hydroxyl, carbonyl, amine, and thiol), proteins, and peptides in biological organisms reduce the vanguard salt to nanoparticles, and this synthesis is simple, repeatable, and constant. Cyanobacteria usage is increasing for green synthesis because of their rich sources of secondary metabolites, pigments, proteins, and peptides that act on the ground of bionanofactories (Sahoo et al., 2020). In addition, they display an easy crop, an economy of scale, and a rapid growth rate. Microalgae are the first organisms that live in various ecosystems and are predominant photosynthetic organisms on land. They can accumulate excessive metals and then transform them into nanoparticles. Different categories of algae, such as green algae, brown algae, red algae, and blue-green algae, produce nanoparticles from metal oxides (Ghasemipour et al., 2017).

The disadvantages of physicochemical approaches contain tardy production velocity, energy consumption, high prices, and above all, these procedures are threatening because of their toxic output that is not environmentally friendly (Patel et al., 2015). The objective of the biological synthesis method is to use natural resources to convert bulk materials into nanoparticles with unique properties. The natural resources used in nanoparticle biomanufacturing range from unicellular to multicellular organisms, and it may also be performed in the presence of enzymes, pigments, and proteins (Geetha et al., 2020).

Unicellular organisms contain diatoms, bacteria, and cyanobacteria, while multicellular organisms contain plants and algae. Diversity in sources and biomolecules makes it possible to produce nanoparticles with unique and different characteristics. Nanoparticle biosynthesis may be managed by a range of physical factors like reaction mixture, contact time, exposure to all sources of light and temperatures, the level of metallic precursor and biological extract, and pH. These factors can change the form, the crystalline nature, and the size of synthesized nanoparticles. Nanoparticles are undergone microscopic and spectroscopic characterization processes to discover their exclusive physicochemical properties after synthesis (Brayner et al., 2007). Determining the exact morphological properties (distribution of particles, form, and size) and nanoparticles' physicochemical quality is crucial in their biomedical and veterinary use (Ismail et al., 2021).

The most common microscopic techniques used to explore the morphological properties and the size of nanoparticles are high-resolution transmission electron microscopy, atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning electron microscopy (SEM) (to analyze the crystallization of the synthesized nanoparticles, composition, and the structure), Fourier transform infrared spectroscopy (FTIR), selected area electron diffraction (SAED), dynamic light scattering (DLS), beam scattering X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), UV-visible spectroscopy (UV-Vis), and energy dispersive spectroscopy (EDS) (Table 1).

Microalgae have a long history of commercial and industrial use as cosmetics, additives, food, fertilizers, pharmaceuticals, bioremediation agents, and feed. The justification for using microalgae for green synthesis is that the synthesis is inexpensive, the reaction is simple, the energy intake is low, and no need for a capping agent or an external reducing agent (Ali et al., 2021).

However, using microalgae to synthesize nanoparticles has created a branch called phyconanotechnology, which is still in its early stages (Lewis Oscar et al., 2016). Therefore, in this review article, we investigated the biosynthesis potential of nanoparticles based on cyanobacteria, the mechanisms involved in the synthesis (extracellular and intracellular), pH, temperature, toxicity of nanoparticles against living cells (Ahari et al., 2022), and the industrial and biomedical and veterinary applications of produced nanoparticles (Table 2).

Mechanisms implicated in nanoparticle biosynthesis through different types of micro-algae

Algae accumulate large amounts of heavy metal ions and can regenerate them into further pliable forms. On account of these attractive features, algae were intended as model organisms for building different kinds of nanomaterials, particularly metal nanoparticles. Nanoparticle biosynthesis starts after incubating the parent metallic solution using an algal extract (Alipour et al., 2021).

There are some biochemical compounds in algae like phycobilins, pigments, antioxidants (Anvar & Nowruzi, 2021), carbohydrates, polyunsaturated fatty acids, oils, fats, chlorophylls, proteins, and minerals that help restore the metal ion charge to zero (Nowruzi et al., 2022; Nowruzi et al., 2020). Bioregeneration contains a threefold procedure wherein the activation phase includes nucleation and reduction of metal ions owing to the enzyme liberation of algal cells, which is revealed by changing the solution's color. Nucleated metallic components are mixed and produce nanoparticles in various shapes and dimensions, which are thermodynamically steady; in the growth stage and the final phase, the final shape of nanoparticles is obtained. Some factors control the physical properties of nanoparticles, for instance, static conditions, agitation, temperature, time, substrate concentration, and pH. Algae nanoparticle biosynthesis may be intracellular or extracellular based on where nanoparticles are formed (Chaudhary et al., 2020).

Nanoparticle intracellular synthesis

The intracellular synthesis of nanoparticles occurs when the reduction of bulk materials into nanoparticles is carried out in the host cells, which is controlled by different biological factors. Based on research studies, spherical and octahedral nanoparticles are deposited in the culture solution and inside the cell following the reaction of the *Plectonema boryanum* UTEX 485 system and the silver nitrate. Also, *P. boryanum* reduces gold chloride solution to gold nanoparticles intracellularly. The researchers suggest nitrate reductase stimulates the enzyme synthesizing nanosilver particles in *Bacillus licheniformis*. Other studies have shown that nitrogenases (nitrogen-fixing enzymes) can convert gold ions into gold nanoparticles as powerful reducing agents (Hanna et al., 2022).

Further research showed that cyanobacterial pigments' function is to reduce bulk materials to nanoparticles intracellularly as a powerful bio-stimulating agent. In addition, nanoparticles were synthesized via chloroauric acid incubation with *Ulva intestinalis* and *Rhizoclonium fontinale* at 20°C for 3 days. Nanoparticle biosynthesis turns the conspicuous violet color of the thallus into the green. The researchers showed that in *Tetraselmis cochinensis*, golden nanoparticles synthesize intracellularly by the algal cell wall, and there was no extracellular synthesis which was proved by UV-visible spectroscopy. Because of the bioactive components responsible for bioregeneration, Nanoparticle density is closer to the cell wall than the cytoplasm (Choi et al., 2021).

Nanoparticle extracellular synthesis

Extracellular synthesis, with the percolation of biological molecules such as hormones, proteins, antioxidants, ions, enzymes, and pigments, play an important task during the nanoparticle regeneration procedure. Various extracellular synthesis methods for nanoparticles include cell biomass extracts, biomolecules, and cell-less culture media. Culture with no nanoparticle cells is synthesized using the microorganism culture medium after the biomass is eliminated via centrifugation (Li et al., 2011).

Then the filtered culture medium is mixed with heavy metals, and nanoparticles are synthesized. The researchers showed that 5 strains of cyanobacteria within a culture medium with no cells of *Synechococcus* sp. could synthesize silver nanoparticles in a state of light. In addition, extracellular silver nanoparticles using the supernatant THG-LS1.4.73 of *Pseudomonas* sp. may synthesize (Ahari et al., 2021).

Some Investigations have demonstrated that some compounds in the cell-free culture, such as phenolic compounds, antioxidants, alkaloid compounds, and enzymes, oversee the bioregeneration of nanoparticles. Biomolecules like sulfur-containing proteins and NADH reductases in cell-less supernatant are suggested to function in the bio-fabrication of metallic nanoparticles (Al-Dhafri & Ching, 2019). Extracellular synthesis takes place when metallic ions are fixed on the surface of algal cells, and they are regenerated by some metabolites like pigments, non-protein, ions, enzymes, proteins, DNA, and lipids. It is easier to do extracellular synthesis because the nanoparticles are easily purified; however, some necessary pretreatments, such as washing, must be performed. Specific physical and chemical conditions like pH, temperature, initial metal/substrate concentration, and type affect the form, aggregation, and size of nanoparticles (Pandy et al., 2020). A higher pH may improve the reduction power of functional groups and, as a result, may inhibit the aggregation of nanoparticles. Neutral pH stabilizes the nanoparticles interacting with the amino groups of surface-bound proteins and their amino acid residues. A peak at the wavelength of 530 nm confirmed the extracellular synthesis of silver nanoparticles manufactured by *Streptomyces platensis* in different densities of chloroauric acid, which indicates the participation of biomolecules, proteins, and enzymes in the synthesis mediated by algae (Uzair et al., 2020).

Nanoparticles synthesis by other groups of algae

Metal nanoparticles like copper, silver, and gold have been widely synthesized from brown algae. Among different metal nanoparticles, more than half of the data reported in the articles relate to the silver nanoparticle synthesis by different algae strains. The reason is that silver nanoparticles have superior physical and chemical properties compared to their bulk forms. In other words, they are very useful for various industries, for instance, textiles, drug delivery, jewelry, wound healing, paints, and dental alloys (Aziz et al., 2021). According to a record, ball-shaped silver nanoparticles (96nm) have been synthesized extracellularly from microalgae *Turbinaria conoides*, which showed excellent antibacterial effects in the face of *Escherichia coli*, *Candida albicans*, *Staphylococcus epidermidis*, *Aspergillus niger*, and *Staphylococcus aureus*. Organic groups, free hydroxyl, polyamines, carbonyl groups, and amines of *Turbinaria* sp. (*T. ornate* and *T. conoides*) act as reducers (Rai, M. et al., 2019).

Silver nanoparticles are widely synthesized by brown algae that have shown several important medicinal biological activities, such as antifouling, anticoagulant, and antibacterial activities. *T. conoides* produces various forms of gold nanoparticles from the extracellular route. In most cases, gold nanoparticles have been synthesized using chloroauric acid as a gold ion precursor with *T. conoides*. *Laminaria japonica* is another species of brown algae that were investigated in the green synthesizing of gold nanoparticles. *L. Japonica* has a copious source of bioactive elements, namely vitamins, fibers, peptides, polyphenols, carotenoids, and proteins. Ball-shaped gold nanoparticles (15-20 nm) have been synthesized extracellularly from *L. Japonica* with the participation of functional groups and phytochemicals acting as reducers (Mandhata et al., 2022). In addition to metal nanoparticles, brown algae are reported regarding the biosynthesis of diverse metal oxide nanoparticles, like titanium oxide and zinc oxide nanoparticles. Synthesized titanium oxide nanoparticles are hexagonal; they are 35 to 57 nm and sheltered by bioactive functional groups, such as carbonyl, amines, hydroxyl, and sulfate (Ahmed et al., 2015). Nanoparticle synthesis from red algae is in its infancy because of slow crystal growth and less stability. However, they are always of interest because they have strong reducing agents, such as sulfated polysaccharides, that include D-galactosyl residues and disaccharides anionic units. Silver nanoparticles manufactured by various strains of red algae are principally 20-60nm in size and spherical (Singh et al., 2020).

Few studies have been conducted on the gold nanoparticle biosynthesis mediated by red algae compared to silver nanoparticles. *Lemanea fluviatilis* is a marine red algae that has been investigated for the biosynthesis of gold nanoparticles using chloroauric acid as a precursor salt. Gold nanoparticles are cubic crystals with a size of 5.9 nm that can be seen by TEM (Rashad et al., 2019). In a separate report, *Corallina officinalis* was also reported for extracellular synthesis of spherical gold nanoparticles with its reductive agents, such as phenol, carbonyl, and hydroxyl functional groups. Besides monometallic nanoparticles, the reddish algae strain *Gracilaria edulis* biosynthesized Ag-Au bimetallic nanoparticles from AgNO3 and HAuCl effectively. These synthesized bimetallic nanoparticles have shown strong anticancer activity against human breast cancer lines (Bakir & Elsemary, 2020).

Blue-green algae *Spirulina platensis* includes 60%-70% plant protein, which has a high amount of iron, essential fatty acid, beta carotene, essential amino acids, and natural vitamins, and that may contribute to the regeneration of nanoparticles (Nowruzi et al., 2021).

Spherical silver nanoparticles (2-8 nm) were synthesized by *S. platensis*, which is used effectively in food industries, pharmacy, and healthcare. Silver nanoparticles were also synthesized in various shapes and sizes from different species of blue-green algae, for example, *P. boryanum* (200 nm, octahedron) and oscillator while (10-25 nm, spherical) (Husain et al., 2015). Various researchers have reported the extracellular synthesis of gold nanoparticles by *S. platensis* in cubic, spherical, and octahedral shapes, which indicates that peptides and proteins are involved as reducing agents. Another major kind of blue-green algae is *Phormidium valderianum* which produced monodispersed intracellular triangular gold nanoparticles on a wavelength of 530 nm with an absorption of 1.8970 through UV-Vis spectroscopy. In addition to monometallic nanoparticles, *S. platensis* was reported in the biosynthesis of bimetallic nanoparticles, like crystalline gold-silver nanoparticles using extracellular proteins. *Chlamydomonas reinhardtii* is also a major species of freshwater green algae that are believed to be participating in producing bimetal *cadmium sulfide* nanoparticles (Hamida et al., 2020).

Cadmium sulfide is special in its optoelectronic features and may be used extensively in LEDs, biosensors, and photocatalysts. Silver nanoparticles synthesized from various species show attractive and changeable physicochemical properties when analyzed by microscopic and spectroscopic methods, for instance, FTIR, EDX, SEM, DLS, and XRD. Almost all types of green microalgae used extracellularly produce silver nanoparticles of different sizes and morphologies, such as *Pithophora oedogonia* (cubic and hexagonal, 24-55 nm), *Chlorococcum humicola* (spherical, 16 nm), *Chlorellanm reinhardtii* (rectangular and round, 1-15 nm) and *Enteromorpha flexuosa* (spherical, 15 nm). Most of the reported metabolites mainly contributed to the biosynthesis of metallic nanoparticles of green microalgae are cyclic compounds, proteins, carboxylic acids, and peptides (Bin-Meferij and Hamida, 2019).

Much effort has been made to synthesize silicon nanoparticles by green microalgae. Silicon nanoparticles are semiconductors. They are biological markers in numerous industrial wastes to detect toxic compounds (Nowruzi & Porzani, 2021). They greatly contribute to the ecological system because they have a crucial role in the production of oxygen and the recycling of nutrients. *C. vulgaris* has been taken into account, and silicon alkaloids have been used as silicon precursors and blended with algae extract. Silicon nanoparticles have been synthesized by hydrolysis and condensation of silicon alkaloids by proteins and peptides in the extract of *C. vulgaris* (Faramarzi & Sadighi, 2013).

An extremely useful species of green macroalgae is *Ulva fasciata*. It has been used to produce nanoscale silver colloids that are primarily demanded in cotton cloth in the presence and absence of citric acid to assess their antimicrobial effect. In a separate report, *Gracilaria edulis*, rich in nitro, carboxylic, and amide compounds, was used to synthesize spherical silver nanoparticles and octahedral zinc nanoparticles. Another major species of marine green algae is *Chaetomorpha linum*, which is known to play an ecological role in the availability of nutrients in its habitat. In addition to silver nanoparticles, gold nanoparticles have been synthesized by macro green algae species such as *Rhizoclonium fontinale* and *Prasiola crispa*. In recent years, gold nanoparticles have received much attention in the targeted delivery of drugs to treat cancer (Afzal et al., 2019).

The researchers showed that spherical silver nanoparticles (96nm) synthesized extracellularly from microalgae demonstrated great antibacterial activity against *Candida albicans*, *Pseudomonas aeruginosa*, *Staphylococcus epidermis*, *Aspergillus niger*, *Staphylococcus aureus*, and *Escherichia coli*. Polyamines-free hydroxyl, carbonyl, amines, and organic compounds are groups of *T. ornate* and *T. comedies* that act as reducing agents. Forerunners of silver salts used in synthesizing silver nanoparticles have been largely synthesized from strains of brown algae, which contain several medicinally important biological activities such as antifouling, anticoagulant, and antibacterial activities among these species (Anvar & Nowruzi, 2021). It has been reported that bimetal nanoparticles have demonstrated strong anticancer activity against human breast cancer lines (Moritz & Geszke-Moritz, 2013).

Spherical silver nanoparticles (2-8 nm) synthesized from *S. platensis* are used successfully in pharmacy, food industries, and healthcare. In addition to *S. platensis*, different species of blue-green algae such as *Microchaete diplosiphon* (spherical, 80nm), *Oscillatoria willei* (spherical, 10-25nm), *Cylindrospermum stagnale* (pentagonal, 38-88nm), and *P. boryanum* (octahedron, 200nm) have synthesized silver nanoparticles in various forms and measures. In addition, reports exist on the biosynthesis of nanogold particles by *S. platensis*. Scientists attributed *S. platensis*'s extracellular synthesis of nanoparticles to the participation of peptides and proteins as reducing agents. In addition to monometallic nanoparticles, *S. platensis* is also able to biosynthesis bimetal nanoparticles, like Ag-Au nanoparticles (Moraes et al., 2021).

Biomedical applications of nanoparticles generated by microalgae

Nanoparticles produced through different green methods are typically free of poisonous substances and biocompatible as they use no reducing agent or outer coating to synthesize nanoparticles. As a result, they are less toxic than chemically synthesized nanoparticles (Porzani et al., 2021). Also, microalgae species do not use poisonous chemicals during the regeneration and stabilization of nanoparticles. Because microalgae species include natural biomolecules that cause less, if any, poisoning, it is, therefore, better to use them in different biomedical applications (Mubarak Ali et al., 2012).

Antibacterial activity

Extensive use of antibiotics in treating bacterial infections resulted in the development of multidrug-resistant bacterial strains. Providing effective and secure therapies for drug-resistant bacterial strains is an important global health challenge (Peidaei et al., 2021). Thus, using nanoparticles has replaced antibacterial agent that has demonstrated superior and effective bactericidal activity. Nanoparticles carry out many antibacterial activities against gram-positive and gram-negative bacteria by destroying the cell membrane and producing reactive oxygen species (ROS) (Ghobashy et al., 2021).

Nanoparticles produced from algae have been investigated because of their antibacterial activity against a broad spectrum of strains of bacteria. The growth of *Bacillus subtilis*, *Klebsiella planticola*, and *P. aeuroginosa* is inhibited by the bio-synthetic silver nanoparticles of the brown algae Padina tetrachromatic. In another study, colloidal stable silver nanoparticles made from a watery extract of marine green algae Caulerpa serrulata have demonstrated special antibacterial capacity at lower concentrations contrary to *P. aeruginosa*, *S. aureus*, *Salmonella typhi, E. Coli,* and *Shigella* sp. (Ahmed et al., 2020).

As a result, the largest 21mm silver (75μL) inhibit zone has been recorded against *E. Coli*, even though the lowest inhibition zone of 10 mm in 50μL of silver nanoparticles has been identified against *Staphylococcus typhi.* The aqueous extract from *Pithophora oedogonia* synthesizes silver nanoparticles with high antibacterial activity against *S. aureus, P. aeruginosa*, *E. Coli*, *Shigella flexneri*, *B. subtilis*, *Vibrio cholerae,* and *Micrococcus luteus.* The greatest inhibit zone (17.2 mm) was observed in *P. aeruginosa*, which shows remarkable antimicrobial activity of silver nanoparticles, contrary to stronger gram-negative bars (Madadi et al., 2021).

Furthermore, spherical gold nanoparticles synthesized from blue-green algae protein extract *S. platensis* were a major inhibitor of the growth of *B. subtilis* and *Staphylococcus aureus*. Scientists have synthesized gold nanoparticles, which were examined for antimicrobial action versus *Aspergillus fumigatus, A. niger, P. aeruginosa, E. Coli, C. albicans, B. subtilis,* and *S. aureus.* Gold nanoparticles manufactured by *Stoechospermum marginatum* showed a better antibacterial effect versus *Enterobacter faecalis* compared to the usual antibiotic tetracycline. In a different investigation, gold and silver nanoparticles were tested by *Neodesmus pupukensis* to assess the antibacterial potential against various bacterial species (Younis et al., 2022).

The findings demonstrate that the silver nanoparticle inhibitory zones were 43mm against *E. Coli*, 27mm against *K. pneumonia*, 39mm against S. marcescens, and 24.5mm against *Pseudomonas* species. However, the force of gold nanoparticles inhibition of *S. marcescens* is 28.5mm, and *Pseudomonas* species is 27.5mm. These results demonstrate the potential implementation of microalgae-mediated nanoparticles as antimicrobial factors in the upcoming (Ravikumar et al., 2012).

Antifungal activity

Due to resistance to antifungal drugs and restricted access to antifungal medicine, fungal infections have become an increasingly serious public health concern, so developing efficient, novel, and strong antifungal agents is very encouraging. Nanoparticles show fantastic antifungal activity, which can be a new choice to treat fungal diseases. Silver nanoparticles are the most effective antifungals replicated with a green procedure. Within an investigation, *Sargassum longifolium* silver nanoparticle synthesis was assessed to evaluate antifungal activity in different densities versus infective fungal strains containing *Fusarium species, C. albicans,* and *Aspergillus fumigatus* (Hamida et al., 2021).

The results have demonstrated that the growth of any fungus was inhibited considerably by silver nanoparticles depending on the dosage. During further research, silver nanoparticles have been synthesized with the aid of the aqueous extract from the red algae *Gelidiella acérosa* and examined for antifungal potency versus *Humicola insolens, Trichoderma reesei, Mucor indicus,* and *Fusarium dimerum*. A high antifungal effect of AgNPs was reported compared with normal antifungal drugs (Priyadarshini et al., 2019).

Silver nanoparticles biosynthetically derivative of the red algae *Hypnea musciformis* and the green algae *Ulva latuca* could also slow the growth of fungal species: *Candida albicans*, *C. parapsilosis,* and *A. niger* (Shaalan et al., 2017). Significant antifungal activity against fungal disintegration of *F. dimerum* and *Humicola insolens* was shown by gold nanoparticles synthesized using an aqueous extract of brown marina algae *Dictyota bartayresiana*. The antifungal effects of silver nanoparticles by inhibiting mycelium are 69.8%, 79.4%, 57.1%, and 80.6% against *Fusarium solani, A. fumigatus, A. flavus,* and *A. niger*, respectively and while gold nanoparticles inhibit 66.4%, 79.4%, 75.4%, 44.3%, and 54.9%, respectively against *C. albicans, A. niger, A. flavus, A. fumigatus,* and *F. solani* (Roychoudhury et al., 2016).

Antifouling activity and prevention of nanoparticle biofilm

The undesirable growth of various groups, for example, algae and fungi, results in economic losses and serious health risks for industrial and medical applications. The use of antifouling compounds, which include the use of poisonous substances, will accumulate and pollute the environment. Nanoparticles may successfully prevent the formation of biofilm resulting from bacterial adherence, and for this reason, they can be an alternative to antifouling agents (Hamouda et al., 2019).

Research shows that silver nanoparticles significantly inhibit the formation of biofilms intractable to gram-negative and gram-positive bacteria containing Salmonella sp. and *E. Coli*. Silver nanoparticles synthesized from *S. ilicifolium* with a diameter between 33 and 40nm show significant toxicity against *A. salina* (Zinicovscaia et al., 2016). Other research studies show that zinc coated with silver nanoparticles synthesized by *T. ornate* inhibits microflora growth. More than 71.9% of *E. coli* and 40% of *Micrococcus* sp. growth was inhibited by silver nanoparticles with biofilm-forming. In addition to silver nanoparticles, copper nanoparticles were also used as anti-biofilm substances to control certain clinical isolates of *P. aeruginosa* (Mandhata et al., 2022).

The findings have demonstrated that copper nanoparticles can restore the hydrophobia of extracellular polymer materials and cell surfaces of *P. aeruginosa*, besides inhibiting biofilm formation (Chaudhary et al., 2020).

In a recent study, silver nanoparticles synthesized by *S. myriocystum* at various concentrations (10, 20, 30, 40, and 50mg/mL) were tested on bacterial strains of *P. aeruginosa* and *S. epidermidis*, which have the highest percentage of biofilms, and inhibition of 67.75% was achieved at 50µg/mL. These findings show that the use of nanoparticles synthesized by algae may become substitutable formulations of antifouling agents shortly (Patel et al., 2014).

Anticancer action of nanoparticles

The use of nanoparticles for cancer treatment and targeted distribution of anticancer medicines is among the most active zones of nano-biotechnology research. In recent years, several studies have been published on the anticancer activities of algal-mediated nanoparticles. Within an investigation, an important anticancer activity against human HeLa cells and HL60 myeloid leukemia cells was shown by *Sargassum vulgare* manufactured silver nanometer (10nm) (Madadi et al., 2021).

Triangular silver nanoparticles coated with algal chitosan polymers act as anticancer agents against human lung cancer cell lines (NCI-H460). Additionally, silver nanoparticles synthesized by *Sargassum muticum* demonstrate cytotoxic effects *in vitro* against the MCF7 breast cancer cell line. Varying amounts of silver nanoparticles (3-50µg/mL) were treated by MCF7 cell lineage for approximately 48h, and the greatest survival percentage of 36% was found to be 12.5µg/mL (Younis et al., 2022).

Nanosilver particles induce intracellular ROS, leading to apoptosis and, ultimately, cancer cell death. Within a different investigation, silver nanoparticles manufactured by S. myriocystum demonstrated significant cytotoxic capabilities against the HeLa cell line through an MTT test. The results show that the HeLa cell line treated with silver nanoparticles was inhibited by 50%, and the overall cytotoxic ability increased with the concentration of silver nanoparticles in the environment (Ravikumar et al., 2012).

Similarly, the potential for cytotoxicity in silver nanoparticles manufactured by algae ex vivo against MCF-7 breast cancer cell line using different amounts (0-100µg/mL) every 24, 36, and 48h was investigated, and the results showed the maximum inhibitory concentration of silver nanoparticles with a concentration of 20µg/mL against breast cancer cells, which led to apoptosis, nuclear fragmentation, and cell death. These results confirmed the anticancer ability of AgNPs. Gold nanoparticles synthesized by algae also demonstrated elevated anticancer activity against different cell lines (San Keskin et al., 2016).

In another study, gold nanoparticles synthesized by *Acanthophora spicifera* showed potent anticancer activity for colorectal adenocarcinoma HT-29. Gold nanoparticles were added at amounts of 30, 15, 7.5, 3.75, and 1.88µg/mL and incubated for 24h and evaluated using the MTT method (Priyadarshini et al., 2019).

The most effective inhibitory amount was 21.86µg/mL, resulting in cell shrinkage, apoptosis, and lack of morphological structure in cancer cell lines. Within a different investigation, gold nanoparticles synthesized by the algae *Chaetomorpha linum* demonstrated significant anticancer potential *in vitro* against colon malignancy cell line HCT-116. Dose-dependent cytotoxic impacts of gold nanoparticles have been reported in lines of colon cancer cells following incubation using these nanoparticles. Also, maximum tumor cells may be killed by gold nanoparticles wrapped in polyethylene glycol (Shaalan et al., 2017).

Nanoparticles biological treatment

Special consideration has recently been given to nanoparticle usage as a novel approach for the biological treatment of contaminated sites. The nanoparticles produced by algae were investigated as bio-remediation factors. For example, silver nanoparticles manufactured by *U. lactuca* catalyzed the degradation of the methyl orange color while processing with seeable light (Roychoudhury et al., 2015).

In a comparable investigation, silver nanoparticles manufactured by Microchaete demonstrate a high discoloration capacity against red methyl azo dyes. A further study demonstrates that gold nanoparticles manufactured with water-based extracts of brown algae *T. conoides* and *S. tenerrimum* have a catalytic effect against rhodamine B, nitroaromatic compounds, and organic sulforhodamine. Also, silver nanoparticles produced by *S. myriocystum* demonstrate a great photocatalytic effect against methylene blue. *Scenedesmus* was therefore found to be an effective model for cadmium ion bioremediation. In this way, various nanoparticles synthesized by algae have demonstrated their positive role in modifying organic/aromatic compounds, various dyes, and heavy metals (Hamouda et al., 2019).

Biosensor

Gold nanoparticles synthesized by algae have shown very good visual features which may be useful in biological sensing functions, for example, measuring the amount and sort of hormones in the human body, especially for diagnosing cancer. Au-Ag, which was synthesized by algae, showed remarkable electrocatalytic power against 2-butanone at ambient temperature, which can serve as a substrate to develop cancer detection biosensors and detect malignant cell's existence in the early stages (Yalcin et al., 2022).

In a recent report, silver nanoparticles synthesized by *Noctiluca scintillans* were evaluated for hydrogen peroxide color assay, which can be used as an antiseptic agent to clean small skin scratches in the mouth, gums, toothache, or whitening and oral secretions act. The breakdown of hydrogen peroxide on the catalytic area of silver nanoparticles depends on pH, temperature, and time (Rahman et al., 2009).

The test also showed a coloring transition from brown to colorless with hydrogen peroxide. In a different investigation, human chorionic gonadotropins discovery capability in expectant women's piss sample during an hCG (human chorionic gonadotropin) pregnancy blood test was shown by gold nanoparticles biosynthesized by *Hypnea valencia*. In addition, platinum nanoparticles produced by *S. myriocystum* act like biosensors to detect the body's levels of adrenaline, a hormonal medicine that is used to cure asthma, heart attacks, and allergies (Velusamy et al., 2016).

Why biosynthesize nanoparticles? Disadvantages of conventional synthetic methods

Over the past few years, chemical and physical methods have been widely used to manufacture nanoparticles. These procedures may deliver huge amounts of nanoparticles of specific size and form within a comparatively short period. However, these procedures create many hazardous toxic wastes. Also, the procedures are complex, old, and expensive (Sahoo et al., 2020).

Current methods for synthesizing nanoparticles rely heavily on highly toxic organic solvents. Physical approaches to producing nanoparticles require much energy, are more costly, provide inaccurate size nanoparticles, and sometimes contain large impurities. Although chemical synthesis occurs more quickly, it contains detriments. Nanoparticle chemical synthesis needs a reactive solvent, a capping, and a reducing agent. Numerous surfactants, including dendrimers, polymers, and long-chain hydrocarbons, are used as covering agents during the production of nanoparticles. However, they do not eliminate easily, they are indecomposable, and particles need a complicated removal process before use in the industry, which raises energy prices (Geetha et al., 2020).

Highly reactive reducers such as formaldehyde, sodium borohydride ($NaBH_4$), and hydrazine (N_2H_4) are used in great quantities during the synthesis procedure, which requires secure transportation and a considerable quantity of which is discarded. In addition, these chemicals need to be eliminated from nanoparticles synthesized for biological applications. Moreover, reactive solvents are used in this process, which provides an environment to dissolve precursors and heat transfer, and the reactions, and the dispersion of the resultant nanoparticles, constitute an environmental hazard (Brayner et al., 2007).

With the evolution of techniques for physically and chemically synthesizing nanoparticles, environmental, security, and health concerns are enhanced. Consequently, the notion of "green nanotechnology" has been considered. Green nanotechnology's durable procedure has a single purpose as a better environment; however, there are two or more routes to achieve this purpose (Sahoo et al., 2020):

1) An eco-friendly method for the generation of nanoparticles.

2) Production of nanomaterials is safe for the environment or human health.

The biological method for nanoparticle forming from microorganisms, plants, fungi, and algae is economical, eco-friendly, and efficient. Nanoparticles produced for pharmaceutical purposes are safe and considerate of the environment. Furthermore, the shelf life and stability of these nanoparticles are longer (Rai, S. et al., 2019). These inexpensive methods are a one-step way of producing nanoparticles (Ismail et al., 2021) with safe processing and enhanced purification. With an enzyme process, lower power is used, costly substances are removed, and an allowable "green" route is taken. For example, the extracellular synthesis of silver nanoparticles by microorganisms is mainly done by synthesizing nitrate reductase. Nicotinamide adenine dinucleotide (NADH) dependent enzyme reductase carries out its activity by reducing Ag*1 to Ag*. In nanoparticle biosynthesis, organisms transform the metallic ions produced into metallic elements in the form and size desired by the enzymes produced by cell activities. Many microorganisms produce minerals within or outside of the cell. The intracellular procedure involves ion transfer through the microbial cell to produce nanoparticles by enzymes (Rajeshkumar et al., 2021).

When the extracellular synthesis of nanoparticles occurs, metallic ions are trapped on the cell surface, and enzymes reduce ions. Several compounds may induce the synthesis of nanoparticles, including flavonoids, pigments, terpenoids, proteins, carbonyl groups, alkaloids, phenolics, amides, amines, and other reducing agents found in microbial cells and herbal extracts. However, the mechanism of nanoparticle synthesis through natural extracts is unknown yet (Cicci et al., 2017).

Function and involvement of cyanobacteria in nanoparticle synthesis

Cyanobacteria have special features, for example, growth on non-cultivable land, increasing soil fertility, high biomass output, beneficial auxiliary products and biofuel production, habitat diversity, reducing greenhouse gas emissions, and oxygen photosynthesis. Their distinctive feature is the conversion of CO_2 to other types

Table 1. Different methods of analyzing the structure, composition, and crystallization of synthesized nanoparticles

Techniques	Analyses	Functions
Spectroscopy technique	UV visible	Confirm the formation of nanoparticles and detect their wavelength range
	Fourier Transform Infrared Spectroscopy	The chemical composition determines the biological coatings around the biogenic nanoparticle
	Zeta potential	Determining the charge of nanoparticles
	Dynamic light scattering (DLS)	Estimation of hydrodynamic diameter
	(NMR)	Determining the content and purity of nanoparticles
X-Ray	X-Ray diffraction (XRD)	Evaluation of composition, structure, and crystalline phase of nanoparticles
	X-ray photoelectron spectroscopy (XPS)	Evaluation of the structure of nanoparticles
	Energy dispersive spectroscopy	Evaluation of the atomic structure of nanoparticles
Microscopic technique	Scanning electron microscope (SEM)	Determination of size and morphological appearance of nanoparticles
	Transmission electron microscope (TEM)	Determination of size and morphological appearance of nanoparticles
	Atomic force microscope (AFM)	Determination of geometry, size, morphology, surface roughness
Magnetic technique	Superconducting quantum interference device (SQUID)	Estimation of magnetic saturation, magnetic retention
	Vibrating sample magnetometer (VSM)	Estimation of magnetic saturation, magnetic retention
	Ferromagnetic resonance (FMR)	Estimation of magnetic saturation, magnetic retention

of carbon stimulated by sunlight, resulting in lower costs to the growing environment. Consequently, the lower production cost of these processes makes cyanobacteria an important source for nanoparticle biosynthesis. The capacity of cyanobacteria to absorb ions at the surface depends on their cell. The surface function is made up of complicated construction in separate layers, which each have unique ionic linking features and special molecular functional groups (Saleh et al., 2015).

Glycoproteins layers cover the outer and inner surface of the cell wall. The rapid attachment of metals to cyanobacteria surface results from extracellular polymers and negatively charged groups on the membrane. Unique metal transport systems exist for entering metals into the cell; for example, purine in the external membrane supports passive and non-selective permeation of metallic ions through the external membrane (Alipour et al., 2021).

Functional groups such as amine, phosphoryl, carboxyl, and hydroxyl placed on the cell wall and exopolymer sheathing collaborate with metallic ions. Cyanobacteria are decent biological systems for the synthesis of intracellular and extracellular ATP. Spirulina can synthesize monometallic and bimetal nanoparticles of gold, silver, and gold-silver extracellularly (Hanna et al., 2022).

Cyanobacteria like Leptolyngbya, Anabaena, and Calothrix synthesize nanoparticles of silver, gold, and palladium intracellularly in controlled size and release them naturally into the culture medium, and prepare for their easy recovery. Studies have shown that particle size and reaction efficiency depend on the cyanobacteria genome. Nostoc linckia cyanobacterium has been used to synthesize selenium nanoparticles from selenite, and finally (Nowruzi et al., 2018) produces extracellular and intracellular amorphous nanoparticles in sizes of 10-80 nm (Table 3).

Golden nanoparticles synthesized by cyanobacteria

Gold nanoparticle generation inside the cell wall of cyanobacteria can be induced by carboxyl groups, polysaccharides, and polyphosphates in the cell wall; this leads to the oxidation of gold ions (Pandy et al., 2020).

Silver nanoparticles synthesized by cyanobacteria

Phycocyanin and polysaccharides obtained from cyanobacteria can regenerate silver ions extracellularly. Phycocyanin pigment and some biological molecules are active factors in the formation of nanoparticles in the external polysaccharide, acting as natural surfactants (covering agents) in the special part of the crystalline formation (Uzair et al., 2022).

Table 2. Synthesis of metal nanoparticles by algae

Algae Species	Metallic Nanoparticles	Synthesis Place	Size (nm)
Ulva fasciata	Silver	Extracellular	28-41
Sargassum plagiophyllum	Silver chloride	Extracellular	18-42
Caulerpa racemose	Silver	Extracellular	2.5-5
Spirulina platensis	Gold	Intracellular	5
Galaxaura elongata	Gold	Extracellular	3.85-77.13
Sargassum wightii Greville	Silver	Extracellular	8-27
Padina pavonica	Silver	Extracellular	54
Chlorella pyrenoidosa	Silver	Extracellular	5-15
Scenedesmus abundans	Silver	Extracellular	59-66
Chlorococcum humicola	Silver	Intracellular	4-6
Bifurcaria bifurcata	Copper oxide	Extracellular	5-45
Amphora	Silver	Extracellular	5-70
Gracilaria dura	Silver	Extracellular	6
Turbinaria conoides	Gold	Extracellular	60

The external polysaccharide layer is an important factor in the accumulation and reduction of metallic ions. It has been observed that hydroxyl and carboxyl groups and active amino exist in polysaccharides' molecular construction, which considerably impacts selenium formation, stabilization, and growth. Sixteen various strains of cyanobacteria and micro-algae have been examined for their capacity to build silver nanoparticles, and 14 of them were efficient. The extracellular environment and cellular extracts can create nanoparticles, which demonstrates the presence of excretory compounds in the extracellular environment, which synthesize nanoparticles in the range between 13 and 30 nm. Studies show that extracellular polysaccharides liberated by algae and cyanobacteria work as regenerative factors in the synthesis of nanoparticles. Research pointed out that C-phycocyanin is an auxiliary blue dye manufactured by cyanobacteria, which may reduce silver and induce the formation of silver nanoparticles (Ishiguro et al., 2021).

Commercial uses of cyanobacterial nanoparticles

Nanoparticle synthesis is done by biological organisms using a nonpoisonous and eco-friendly procedure. Nanoparticles can be synthesized in various sizes, forms, and structures, as well as physical and chemical features. The biological creation of well-qualified and steady nanoparticles may be achieved by developing critical characteristics, for example, enzyme activity, organism type, and cell growth rate. Proteins and enzymes in the biological system offer the extractive capacity for the manufactured nanoparticles. As a result, a further step on the way to "green synthesis" is to avoid the use of chemical stabilizers (Aziz et al., 2021).

In some cases, the nanoparticles produced remain in the culture media to produce steady colloids, making retrieval easier. Biosynthetic nanoparticles are nonpoisonous and used for biomedical and clinical applications, for instance, in gene therapy, biosensors, MRI, cancer therapy, DNA analysis, drug carriers for targeted delivery, as antibacterial agents, and to increase reaction speed (Mandhata et al., 2022). These biological products are also better suited for cosmetic use as they are less sensitive. Nanoparticles produced by biological methods protect natural and non-renewable resources and reduce environmental pollution (Nowruzi, 2022).

Various metal nanoparticles like copper, platinum, gold, palladium, and silver have been successfully biosynthesized with green reduction agents (Singh et al., 2020). For example, biosynthetic nanoparticles like gold nanoparticles may be gathered within tumors, and their exceptional chemical and visual features may be used in tumor ther-

Table 3. Silver nanoparticles synthesized with different cyanobacterial strains

Species	Reaction Time (h)	Shape	Maximum Absorption (nm)	Size (nm)
Arthrospira indica PCC7940	45	Spherical	446	48
Arthrospira indica SAE-85	45	Spherical	468	67
Arthrospira indica SOSA-4	46	Spherical	446	48
Arthrospira maxima SAE-49-88	48	Triquetrum	465	61
Arthrospira platensis NEERI	45	Triquetrum	445	46
Chroococcus NCCU-207	120	Spherical	447	48
Gloeocapsa gelatinosa NCCU-430	50	Spherical	490	88
Lyngbya NCCU-102	120	Spherical	452	54
Oscillatoria sp. NCCU-369	360	Spherical	485	80
Phormidium sp. NCCU-104	96	Tetragone	446	48
Plectonema sp. NCCU-204	320	Spherical	460	61
Spirulina CFTRI	46	Hexagone	446	47
Spirulina NCCU-477	45	Tetragone	450	49
Spirulina NCCU-479	45	Spherical	452	52
Spirulina-481	45	Spherical	466	64
Spirulina NCCU-482	45	Spherical	443	42
Spirulina NCCU-483	47	Pentagon	450	51
Spirulina platensis NCCU-S5	45	Spherical	445	46
Synechocystis NCCU-370	72	Spherical	485	80
Anabaena ambigua NCCU-1	72	Spherical	446	48
Anabaena variabilis NCCU-441	72	Spherical	450	50
Aulosira fertilissma NCCU-443	50	Spherical	450	58
Calothrix brevissema NCCU-65	220	Tetragone	443	42
Cylindrospermum stagnale NCCU	250	Pantagon	440	38,40
Hapalosiphon fontinalis NCCU-339	270	Triquetrum	450	50
Microchaete sp. NCCU-342	30	Spherical	440	40
Nostoc muscorum NCCU-442	220	Spherical	443	42
Scytonema sp. NCCU-126	350	Spherical	470	70
Tolypothrix tenuis NCCU-122	300	Spherical	445	44
Westiellopsis prolifica NCCU-331	280	Spherical	451	52

mal cures. Research has demonstrated that biocompatible gold nanoparticles are vectors for the targeted delivery of anticancer drugs; consequently, they improve transfer and minimize treatment time and reduce side effects. Some diagnostic kits with the base of gold nanoparticles are in the clinical trial phase, and they are used to recognize diseases like HIV and cancer. Green synthetic gold nanoparticles are also used to develop biosensors and determine blood sugar levels, insecticides, poisonous metals, and disease markers (Rashad et al., 2019).

Gold nanoparticles are antibacterial agents and respond with bases containing phosphorus or sulfur in proteins. Nanoparticles cut off the respiratory chains by generating many free radicals when they link to the thiol parts of enzymes, like NADH dehydrogenases, which cause metabolic stress. In addition, gold nanoparticles can prevent the bond between RNA-t and the ribosomal subunit. Gram-negative and gram-positive bacteria are constrained by biosynthetic silver nanoparticles due to their germicidal impacts. The preparation of essential proteins for synthesizing adenosine triphosphate and some cell enzymes can be disbanded by silver ions released by silver nanoparticles. Also, they can affect the bacterial DNA replication function in contact with bacterial cells. Silver ions can break the function of membranous enzymes in the respiratory chain.

Zinc oxide nanoparticles exhibit great bactericidal potency; also, they are used for sewerage treatment and food packaging (Ahari et al., 2022). In addition, using zinc oxide nanoparticles in cosmetic products such as sunscreens causes fewer allergic symptoms (Pandy et al., 2020; Chaudhary et al., 2020; Nowruzi et al., 2020). Biosynthetic nanoparticles are better suited to orthopedic implants because they are more adaptable to bone cells (osteoblasts), and they can manufacture a new bone matrix, thereby improving the mean lifespan of the implant. Biosynthetic bone fillers may present a lower potential for rejection and toxicity (Husain et al., 2015).

Study limitations and future applications

Microalgae have always been of interest as the best applicants to green synthesize nanoparticles because they contain an abundant source of secondary metabolites acting as a capping and regenerative agent. However, nanoparticle synthesis is at the beginning and is not suitable for commercial use. There are many limits to nanoparticle biosynthesis by algae, and one is the slow kinetics of reactions, which may take several days to weeks. Furthermore, microalgae usage in nanoparticle manufacturing is limited due to little information about the synthetic mechanism. In addition, significant studies are necessary to determine the function of particular biomolecules that coat and reduce nanoparticles in the process of algal mediation biosynthesis. A finite amount of nanoparticles and other nanoparticle syntheses such as silicon, palladium, and zinc oxide may be studied in the future. With the emergence of new technologies, it is possible to perform a controlled and comparative synthesis of nanoparticles based on microalgae, which helps improve the quality of microalgae-mediated nanoparticles for industrial applications.

2. Conclusion

The major challenges often encountered in nanoparticle biosynthesis are controlling the form and size of particles in solution. Cyanobacteria is the best host for synthesizing intracellular and extracellular nanoparticles because of lower energy requirements in culture and shorter production times. Of course, the synthesis of cyanobacterial-mediated nanoparticles is mostly done at the laboratory level. Therefore, further studies should examine the enzymatic mechanisms and proteins responsible for nanoparticle manufacturing. Considering the diversity of cyanobacteria, they are always needed for nanoparticle biosynthesis. Indeed, nanoparticle biosynthesis by cyanobacteria is a relatively new idea in the development phase. However, we should optimize various factors for the biosynthesis of nanoparticles.

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Compliance with ethical guidelines

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References

Afzal, B., Yasin, D., Husain, S., Zaki, A., Srivastava, P., & Kumar, R., et al. (2019). Screening of cyanobacterial strains for the selenium nanoparticles synthesis and their antioxidant activity. *Biocatalysis and Agricultural Biotechnology, 21*, 101307. [DOI:10.1016/j.bcab.2019.101307]

Ahari, H., Nowruzi, B., Anvar, A. A., & Porzani, S. J. (2022). The toxicity testing of cyanobacterial toxins in vivo and *in vitro* by mouse bioassay: A review. *Mini Reviews in Medicinal Chemistry*, *22*(8), 1131-1151. [PMID]

Ahmed, F., Soliman, F. M., Adly, M. A., Soliman, H., El-Matbouli, M., & Saleh, M. (2020). *In vitro* assessment of the antimicrobial efficacy of chitosan nanoparticles against major fish pathogens and their cytotoxicity to fish cell lines. *Journal of Fish Diseases*, *43*(9), 1049-1063. [DOI:10.1111/jfd.13212] [PMID] [PMCID]

Ahmed, E. A., Hafez, E. H. A., Ismail, A. F. M., Elsonbaty, S. M., Abbas, H., & Eldin, R. A. S. (2015). Biosynthesis of silver nanoparticles by *Spirulina platensis* and Nostoc sp. *Global Advanced Research Journal of Microbiology*, *4*(4), 36-49. [Link]

Al-Dhafri, K., & Ching, C. L. (2019). Phyto-synthesis of silver nanoparticles and its bioactivity response towards nosocomial bacterial pathogens. *Biocatalysis and Agricultural Biotechnology*, *18*, 101075. [DOI:10.1016/j.bcab.2019.101075]

Ali, S., Paul Peter, A., Chew, K. W., Munawaroh, H., & Show, P. L. (2021). Resource recovery from industrial effluents through the cultivation of microalgae: A review. *Bioresource Technology*, *337*, 125461. [DOI:10.1016/j.biortech.2021.125461] [PMID]

Alipour, S., Kalari, S., Morowvat, M. H., Sabahi, Z., & Dehshahri, A. (2021). Green synthesis of selenium nanoparticles by cyanobacterium *Spirulina platensis* (abdf2224): Cultivation condition quality controls. *Biomed Research International*, *2021*, 6635297. [DOI:10.1155/2021/6635297] [PMID] [PMCID]

Anvar, A. A., & Nowruzi, B. (2021). Bioactive properties of spirulina: A review. *Microbial Bioactives*, *4*(1), 134-142. [DOI:10.25163/microbbioacts.412117B0719110521]

Anvar, S. A. A., & Nowruzi, B. (2021). [A review of phycobiliproteins of cyanobacteria: structure, function and industrial applications in food and pharmaceutical industries (Persian)]. *Research and Innovation in Food Science and Technology*, *10*(2), 181-198. [DOI:10.22101/JRIFST.2021.288378.1247]

Anvar, S. A. A., Nowruzi, B., & Tala, M. (2021). [Products of cyanobacteria and microalgae as valuable dietary and medicinal supplements (Persian)]. *Food Hygiene*, *11*(1), 99-118. [DOI:10.30495/JFH.2021.1925461.1310]

Aziz, N., Zaki, A., Ahamad, I., & Fatma, T. (2021). Silver nanoparticle synthesis from cyanobacteria: Environmental and biomedical applications. In J. K. Patel, & Y. N. Pathak (Eds.), *Emerging technologies for nanoparticle manufacturing* (pp. 461-472). Cham: Springer. [DOI:10.1007/978-3-030-50703-9_21]

Bakir, E., & ElSemary, N. (2020). Cyanobacteria as nanogold Factories: The chemical validation and perspective of the association between gold nanoparticles and cyanobacterial glycogen. 2020; 1-15. [Unpublished] [DOI:10.21203/rs.3.rs-45902/v1]

Bin-Meferij, M. M., & Hamida, R. S. (2019). Biofabrication and antitumor activity of silver nanoparticles utilizing novel nostoc sp. Bahar M. *International Journal of Nanomedicine*, *14*, 9019–9029. [PMID] [PMCID]

Brayner, R., Barberousse, H., Hemadi, M., Djedjat, C., Yéprémian, C., & Coradin, T., et al. (2007). Cyanobacteria as bioreactors for the synthesis of Au, Ag, Pd, and Pt nanoparticles via an enzyme-mediated route. *Journal of Nanoscience and Nanotechnology*, *7*(8), 2696-2708. [DOI:10.1166/jnn.2007.600] [PMID]

Chaudhary, R., Nawaz, K., Khan, A. K., Hano, C., Abbasi, B. H., & Anjum, S. (2020). An overview of the algae-mediated biosynthesis of nanoparticles and their biomedical applications. *Biomolecules*, *10*(11), 1498. [DOI:10.3390/biom10111498] [PMID] [PMCID]

Choi, B., Park, W., Park, S. B., Rhim, W. K., & Han, D. K. (2020). Recent trends in cell membrane-cloaked nanoparticles for therapeutic applications. *Methods (San Diego, Calif.)*, *177*, 2–14. [DOI:10.1016/j.ymeth.2019.12.004] [PMID]

Cicci, A., Sed, G., Tirillò, J., Stoller, M., & Bravi, M. (2017). Production and characterization of silver nanoparticles in cultures of the cyanobacterium A. platensis (Spirulina). *Chemical Engineering Transactions*, *57*, 1405-1410. [Link]

Faramarzi, M. A., & Sadighi, A. (2013). Insights into biogenic and chemical production of inorganic nanomaterials and nanostructures. *Advances in Colloid and Interface Science*, *189-190*, 1-20. [DOI:10.1016/j.cis.2012.12.001] [PMID]

Ghasemipour, T., Salehzadeh, A., & S adat Shandiz, S. A. (2017). [Biosynthesis of silver nanoparticles using oscillatoria extract and evaluation the anticancer and antibacterial activities (Persian)]. *Armaghane Danesh*, *22*(4), 459-471. [Link]

Geetha, S., Vijayakumar, K., Aranganayagam, K. R., & Thiruneelakandan, G. (2020). Biosynthesis, characterization of silver nanoparticles and antimicrobial screening by Oscillatoria Annae. *AIP Conference Proceedings*, *2270*(1), 110026. [DOI:10.1063/5.0024262]

Ghobashy, R. S., Elsheekh, M. M., Ismail, G. A., & Gheda, S. F. (2021). Biosynthesis of metal nanoparticles using blue-green algae (Cyanobacteria) and their possible applications: Thesis Abstract. *International Journal of Cancer and Biomedical Research*, *5*(0), 6-6. [DOI:10.21608/jcbr.2021.59664.1133]

Hamida, R. S., Abdelmeguid, N. E., Ali, M. A., Bin-Meferij, M. M., & Khalil, M. I. (2020). Synthesis of silver nanoparticles using a novel cyanobacteria desertifilum sp. extract: Their antibacterial and cytotoxicity effects. *International Journal of Nanomedicine*, *15*, 49-63. [PMID] [PMCID]

Hamida, R. S., Ali, M. A., Redhwan, A., & Bin-Meferij, M. M. (2020). Cyanobacteria-A promising platform in green nanotechnology: A review on nanoparticles fabrication and their prospective applications. *International Journal of Nanomedicine*, *15*, 6033–6066. [PMID] [PMCID]

Hamida, R. S., Ali, M. A., Goda, D. A., & Redhwan, A. (2021). Anticandidal potential of two cyanobacteria-synthesized silver nanoparticles: Effects on growth, cell morphology, and key virulence attributes of *Candida albicans*. *Pharmaceutics*, *13*(10), 1688. [PMID] [PMCID]

Hamouda, R. A., Hussein, M. H., Abo-Elmagd, R. A., & Bawazir, S. S. (2019). Synthesis and biological characterization of silver nanoparticles derived from the cyanobacterium Oscillatoria limnetica. *Scientific Reports*, *9*(1), 13071. [DOI:10.1038/s41598-019-49444-y] [PMID] [PMCID]

Hanna, A. L., Hamouda, H. M., Goda, H. A., Sadik, M. W., Moghanm, F. S., & Ghoneim, A. M., et al. (2022). Biosynthesis and characterization of silver nanoparticles produced by phormidium ambiguum and desertifilum tharense cyanobacteria. *Bioinorganic Chemistry and Applications, 2022*, 9072508. [DOI:10.1155/2022/9072508] [PMID] [PMCID]

Husain, S., Sardar, M., & Fatma, T. (2015). Screening of cyanobacterial extracts for synthesis of silver nanoparticles. *World Journal of Microbiology and Biotechnology, 31*(8), 1279-1283. [DOI:10.1007/s11274-015-1869-3] [PMID]

Ishiguro, S., Gbore, D., Calo, G., & Tamura, M. (2021). A potential application of algae as a complementary/integrative therapy in veterinary medicine. *Journal of Veterinary Sciences, 2581-3897*, 1-10. [Link]

Ismail, G. A., Allam, N. G., El-Gemizy, W. M., & Salem, M. A. (2021). The role of silver nanoparticles biosynthesized by Anabaena variabilis and *Spirulina platensis* cyanobacteria for malachite green removal from wastewater. *Environmental Technology, 42*(28), 4475-4489. [PMID]

LewisOscar, F., Vismaya, S., Arunkumar, M., Thajuddin, N., Dhanasekaran, D., & Nithya, C. (2016). Algal nanoparticles: Synthesis and biotechnological potentials. In N. Thajuddin, & D. Dhanasekaran (Eds), *Algae-organisms for imminent biotechnology* (pp. 157-182). London: IntechOpen. [DOI:10.5772/62909]

Li, X., Xu, H., Chen, Z. S., & Chen, G. (2011). Biosynthesis of nanoparticles by microorganisms and their applications. *Journal of Nanomaterials, 2011*, 1-8. [DOI:10.1155/2011/270974]

Madadi, R., Maljaee, H., Serafim, L. S., & Ventura, S. P. (2021). Microalgae as contributors to produce biopolymers. *Marine Drugs, 19*(8), 466. [DOI:10.3390/md19080466] [PMID] [PMCID]

Mandhata, C. P., Sahoo, C. R., & Padhy, R. N. (2022). Biomedical applications of biosynthesized gold nanoparticles from cyanobacteria: An overview. *Biological Trace Element Research, 200*(12), 5307–5327. [DOI:10.1007/s12011-021-03078-2] [PMID]

Moraes, L. C., Figueiredo, R. C., Ribeiro-Andrade, R., Pontes-Silva, A. V., Arantes, M. L., & Giani, A., et al. (2021). High diversity of microalgae as a tool for the synthesis of different silver nanoparticles: A species-specific green synthesis. *Colloid and Interface Science Communications, 42*, 100420. [DOI:10.1016/j.colcom.2021.100420]

Moritz, M., & Geszke-Moritz, M. (2013). The newest achievements in synthesis, immobilization and practical applications of antibacterial nanoparticles. *Chemical Engineering Journal, 228*, 596-613. [DOI:10.1016/j.cej.2013.05.046]

MubarakAli, D., Gopinath, V., Rameshbabu, N., & Thajuddin, N. (2012). Synthesis and characterization of CdS nanoparticles using C-phycoerythrin from the marine cyanobacteria. *Materials Letters, 74*, 8-11. [DOI:10.1016/j.matlet.2012.01.026]

Nowruzi, B. (2022). [A review of bioactive compounds of cyanobacteria and microalgae as cosmetically useful supplements (Persian)]. *Journal of Dermatology and Cosmetic, 12*(4), 256-269. [Link]

Nowruzi, B., Bouaïcha, N., Metcalf, J. S., Porzani, S. J., & Konur, O. (2021). Plant-cyanobacteria interactions: Beneficial and harmful effects of cyanobacterial bioactive compounds on soil-plant systems and subsequent risk to animal and human health. *Phytochemistry, 192*, 112959. [DOI:10.1016/j.phytochem.2021.112959] [PMID]

Nowruzi, B., Fahimi, H., & Lorenzi, A. S. (2020). Recovery of pure C-phycoerythrin from a limestone drought tolerant cyanobacterium Nostoc sp. and evaluation of its biological activity. *Anales de Biología, 42*, 115-128. [DOI:10.6018/analesbio.42.13]

Nowruzi, B., Haghighat, S., Fahimi, H., & Mohammadi, E. (2018). Nostoc cyanobacteria species: a new and rich source of novel bioactive compounds with pharmaceutical potential. *Journal of Pharmaceutical Health Services Research, 9*(1), 5-12. [DOI:10.1111/jphs.12202]

Nowruzi, B., Jafari, M., Babaie, S., Motamedi, A., & Anvar, A. (2020). [Spirulina: A healthy green sun with bioactive properties (Persian)]. *Journal of Microbial World, 13*(4), 322-348. [Link]

Nowruzi, B., Konur, O., & Anvar, S. A. A. (2022). The stability of the phycobiliproteins in the adverse environmental conditions relevant to the food storage. *Food and Bioprocess Technology, 15*, 2646-2663. [DOI:10.1007/s11947-022-02855-8]

Nowruzi, B., & Porzani, S. J. (2020). Toxic compounds produced by cyanobacteria belonging to several species of the order Nostocales: A review. *Journal of Applied Toxicology, 41*(4), 510-548. [DOI:10.1002/jat.4088] [PMID]

Nowruzi, B., Sarvari, G., & Blanco, S. (2020). The cosmetic application of cyanobacterial secondary metabolites. *Algal Research, 49*, 101959. [DOI:10.1016/j.algal.2020.101959]

Peidaei, F., Ahari, H., Anvar, S. A. A., & Ataee, M. (2021). Nanotechnology in food packaging and storage: A review. *Iranian Journal of Veterinary Medicine, 15*(2), 123-153. [Link]

Pandey, S. N., Verma, I., & Kumar, M. (2020). Cyanobacteria: Potential source of biofertilizer and synthesizer of metallic nanoparticles. In P. Kumar, & A. Kumar (Eds.), *Advances in cyanobacterial biology* (pp. 351-367). Cambridge: Academic Press. [DOI:10.1016/B978-0-12-819311-2.00023-1]

Patel, V., Berthold, D., Puranik, P., & Gantar, M. (2014). Screening of cyanobacteria and microalgae for their ability to synthesize silver nanoparticles with antibacterial activity. *Biotechnology Reports, 5*, 112-119. [DOI:10.1016/j.btre.2014.12.001] [PMID] [PMCID]

Porzani, S. J., Lima, S. T., Metcalf, J. S., & Nowruzi, B. (2021). In vivo and *in vitro* toxicity testing of cyanobacterial toxins: A mini-review. *Reviews of Environmental Contamination and Toxicology, 258*, 109-150. [DOI:10.1007/398_2021_74] [PMID]

Priyadarshini, E., Priyadarshini, S. S., & Pradhan, N. (2019). Heavy metal resistance in algae and its application for metal nanoparticle synthesis. *Applied Microbiology and Biotechnology, 103*(8), 3297-3316. [DOI:10.1007/s00253-019-09685-3] [PMID]

Rahman, A., Ismail, A., Jumbianti, D., Magdalena, S., & Sudrajat, H. (2009). Synthesis of copper oxide nano particles by using Phormidium cyanobacterium. I*ndonesian Journal of Chemistry, 9*(3), 355-360. [DOI:10.22146/ijc.21498]

Rai, M., Ingle, A. P., Gupta, I., Pandit, R., Paralikar, P., & Gade, A., et al. (2019). Smart nanopackaging for the enhancement of food shelf life. *Environmental Chemistry Letters, 17*, 277-290. [DOI:10.1007/s10311-018-0794-8]

Rai, S., Wenjing, W., Shrivastava, A. K., & Singh, P. K. (2019). Cyanobacteria as a source of nanoparticles and their applications. In A. Kumar, A. Kishore Singh,& K. Kumar Choudhary (Eds.), *Role of plant growth promoting microorganisms in sustainable agriculture and nanotechnology* (pp. 183-198). Sawston: Woodhead Publishing. [DOI:10.1016/B978-0-12-817004-5.00011-7]

Rajeshkumar, S., Tharani, M., Rajeswari, V. D., Alharbi, N. S., Kadaikunnan, S., & Khaled, J. M., et al. (2021). Synthesis of greener silver nanoparticle-based chitosan nanocomposites and their potential antimicrobial activity against oral pathogens. *Green Processing and Synthesis, 10*(1), 658-665. [DOI:10.1515/gps-2021-0060]

Rashad, S., A El-Chaghaby, G. A., & Elchaghaby, M. A. (2019). Antibacterial activity of silver nanoparticles biosynthesized using *Spirulina platensis* microalgae extract against oral pathogens. *Egyptian Journal of Aquatic Biology and Fisheries, 23*(5 Special Issue), 261-266. [DOI:10.21608/ejabf.2019.65907]

Ravikumar, S., Gokulakrishnan, R., & Raj, J. A. (2012). Nanoparticles as a source for the treatment of fish diseases. *Asian Pacific Journal of Tropical Disease, 2*(Supplement 2), S703-S706. [DOI:10.1016/S2222-1808(12)60247-3]

Roychoudhury, P., Ghosh, S., & Pal, R. (2016). Cyanobacteria mediated green synthesis of gold-silver nanoalloy. *Journal of Plant Biochemistry and Biotechnology, 25*(1), 73-78. [DOI:10.1007/s13562-015-0311-0]

Sahoo, C. R., Maharana, S., Mandhata, C. P., Bishoyi, A. K., Paidesetty, S. K., & Padhy, R. N. (2020). Biogenic silver nanoparticle synthesis with cyanobacterium Chroococcus minutus isolated from Baliharachandi sea-mouth, Odisha, and *in vitro* antibacterial activity. *Saudi Journal of Biological Sciences, 27*(6), 1580-1586. [DOI:10.1016/j.sjbs.2020.03.020] [PMID] [PMCID]

San Keskin, N. O., Koçberber Kılıç, N., Dönmez, G., & Tekinay, T. (2016). Green synthesis of silver nanoparticles using cyanobacteria and evaluation of their photocatalytic and antimicrobial activity. *Journal of Nano Research, 40,* 120-127. [DOI:10.4028/www.scientific.net/JNanoR.40.120]

Saleh, M., Soliman, H., & El-Matbouli, M. (2015). Gold nanoparticles as a potential tool for diagnosis of fish diseases. *Methods in Molecular Biology (Clifton, N.J.), 1247*, 245-252. [DOI:10.1007/978-1-4939-2004-4_19] [PMID]

Shaalan, M. I., El-Mahdy, M. M., Theiner, S., El-Matbouli, M., & Saleh, M. (2017). *In vitro* assessment of the antimicrobial activity of silver and zinc oxide nanoparticles against fish pathogens. *Acta Veterinaria Scandinavica, 59*(1), 49. [DOI:10.1186/s13028-017-0317-9] [PMID] [PMCID]

Singh, Y., Kaushal, S., & Sodhi, R. S. (2020). Biogenic synthesis of silver nanoparticles using cyanobacterium Leptolyngbya sp. WUC 59 cell-free extract and their effects on bacterial growth and seed germination. *Nanoscale Advances, 2*(9), 3972-3982. [DOI:10.1039/D0NA00357C] [PMID] [PMCID]

Uzair, B., Liaqat, A., Iqbal, H., Menaa, B., Razzaq, A., & Thiripuranathar, G., et al. (2020). Green and cost-effective synthesis of metallic nanoparticles by algae: Safe methods for translational medicine. *Bioengineering, 7*(4), 129. [DOI:10.3390/bioengineering7040129] [PMID] [PMCID]

Velusamy, P., Kumar, G. V., Jeyanthi, V., Das, J., & Pachaiappan, R. (2016). Bio-inspired green nanoparticles: Synthesis, mechanism, and antibacterial application. *Toxicological Research, 32*(2), 95-102. [DOI:10.5487/TR.2016.32.2.095] [PMID] [PMCID]

Yalçın, D., Erkaya, İ. A., & Erdem, B. (2022). Antimicrobial, antibiofilm potential, and anti-quorum sensing activity of silver nanoparticles synthesized from Cyanobacteria Oscillatoria princeps. *Environmental Science and Pollution Research,* 1-15. [DOI:10.1007/s11356-022-22068-y]

Younis, N. S., Mohamed, M. E., & El Semary, N. A. (2022). Green synthesis of silver nanoparticles by the cyanobacteria synechocystis sp.: Characterization, antimicrobial and diabetic wound-healing actions. *Marine Drugs, 20*(1), 56. [DOI:10.3390/md20010056] [PMID] [PMCID]

Zinicovscaia, I., Rudi, L., Valuta, A., Cepoi, L., Vergel, K., & Frontasyeva, M. V., et al. (2016). Biochemical changes in Nostoc linckia associated with selenium nanoparticles biosynthesis. *Ecological Chemistry and Engineering, 23*(4), 559-569. [DOI:10.1515/eces-2016-0039]

مقاله مروری

مروری بر کاربرد پزشکی نانوذرات بیوسنتز شده توسط ریز جلبک ها وسیانوباکتری ها در علوم پزشکی و دامپزشکی

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چکیده

سنتز سبز نانوذرات یک روش سازگار با محیط زیست برای تولید نانوذرات با خواص بیولوژیکی، فیزیکی و شیمیایی منحصر به فرد است. امروزه روش‌های سنتز بیولوژیکی به دلیل معایب سنتز فیزیکی و شیمیایی که شامل بازده سمی، زمان و مصرف انرژی و هزینه بالا است، بسیار قابل توجه است. در میان میکروارگانیسم های مختلف، سیانوباکتری ها به دلیل توانایی در انباشت فلزات سنگین از محیط زیست و همچنین تولید انواع ترکیبات زیست فعال مانند رنگدانه ها و آنزیم‌ها، کاندیدای مناسبی به عنوان عوامل احیا کننده و تثبیت کننده هستند. در واقع سنتز سبز نانوذرات توسط سیانوباکتری ها، به عنوان یک پروتکل ایمن، ساده، پایدار، مقرون به صرفه و سازگار با محیط زیست برای کاربردهای زیست پزشکی و دامپزشکی، توجه گسترده‌ای را به خود جلب کرده است. در این میان متابولیت‌های ثانویه سنتز شده توسط سیانوباکتری ها با قابلیت احیای فلزات و اکسید فلزات به صورت داخل و خارج سلولی، بسیار قابل توجه هستند و دارای پتانسیل ضد باکتری، ضد قارچ، ضد جلبک، ضد سرطان، و فعالیت های فوتوکاتالیستی هستند. مقاله مروری حاضر، ویژگی‌ها وکاربردهای زیست پزشکی و دامپزشکی نانوذرات تولید شده توسط سیانوباکتری ها مورد بررسی قرار می گیرد.

کلیدواژه‌ها: ریز جلبک ها. سنتر سبز. نانوذرات، کاربردهای زیست پزشکی، سیانوباکتری ها.

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