

Algae: A Prospective Source for Nanoparticle Production with Some Potential Applications and Limitations

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ABSTRACT

In order to achieve a large-scale circular economy, it is necessary to create environmentally friendly alternatives to the traditional physicochemical pathways for nanomaterials, which pose risks to the environment. You may use algae from the Cyanophyceae, Chlorophyceae, Phaeophyceae, and Rhodophyceae families as nanomachinery. These algae can synthesize metallic nanoparticles, such as gold (Au), silver (Ag), and others, both within and outside of their cells. A variety of biocompatible reductants, including pigments and antioxidants, are found in algae cell extracts, which make them an attractive platform for the manufacture of nanomaterials. Nanoparticles having antibacterial characteristics, possibly replacing current antibiotics, have been thoroughly investigated in *Chlorella* and *Sargassum* spp. We used state-of-the-art spectroscopic, diffractographic, and microscopic techniques, such as UV-Vis FT-IR, DLS, XPS, XRD, SEM, TEM, AFM, HR-TEM, to characterize nanoparticles (NPs) made from algae.

Keywords: Spectroscopic, Nanoparticles, UV-Vis FT-IR, freshwater algae.

INTRODUCTION

"Nanos"—"dwarf" in Greek—is the origin of the prefix "nano" in nanotechnology. According to Hulkoti, a nanometer is any man-made substance with a size or dimension smaller than one billionth of a millimeter (10⁻⁹ m). Advancements in nanotechnology, such as the creation, application, and utilization of nanomaterials in biological research, have resulted from the collaboration of engineering and medical sciences. The field of nano-biotechnology focuses on the use of biological moieties to impart desired characteristics onto nanoscale particles. Because of their distinct characteristics when contrasted with their bulk equivalents, nanomaterials synthesized in a variety of sizes and forms have garnered considerable interest. Because nanoscale materials have a very high surface area to volume ratio, their chemical, biological, and physicochemical properties are quite varied. Because of this, there are noticeable changes in mechanical properties, electrical and thermal conductivity, optical absorption, melting point, and biological and catalytic activity [2]. Because of their minuscule size, irregular form, and dispersed size, nanoparticles display distinctive chemical, physical, electrical, optical, thermal, mechanical, and biological characteristics in comparison to their bulk-scale equivalents. Metallic nanoparticles possess potential applications across various fields, including electronics, cosmetics, coatings, packaging, and biotechnology.[3] It possesses the capability to bind to individual strands of DNA without inducing any damage to the chain [4].

Despite the fact that they are used in a variety of biotechnological applications, including hazardous metal clean-up [5], bacterial and fungal organisms have been classified as prospective nanofactories that have the potential to provide environmental benefits. There has been the emergence of a novel and mostly unexplored area of research that is focused on the use of a wide range of organisms in the biosynthesis of nanomaterials. This field of study was inspired by natural processes that were generated by nature for the manufacture of inorganic materials on nano- and micro-length scales [6]. It has been reported that metal nanoparticles may be biosynthesized by making use of a variety of microorganisms, including bacteria, yeasts, and actinomycetes, in addition to fungi and plants [7].

Some types of algae, which are eukaryotic and oxygenic photoautotrophs in water, may collect heavy metals. Algal biosynthesis of noble metal nanoparticles is, however, an area that has received less attention. The dried, single-celled green algae *Chlorella vulgaris* forms algal-bound gold, which is subsequently reduced to Au(0), by building a strong bond with tetrachloroaurate ions. Inside and outside the cells, tetrahedral, decahedral, and icosahedral gold crystals formed, and 11% of the gold linked to the algae went into a metallic condition. [8] As an edible blue-green algae, dried *Spirulina platensis* allowed for the extracellular synthesis of Au/Ag bimetallic nanoparticles in addition to gold and silver. The creation of extracellular metal bionanoparticles was investigated in a more recent study using *Sargassum wightii* and *Kappaphycus alvarezii*, respectively [9]. Another study by Senapati et al. confirmed the utilization of

Tetraselmis Chinensis for the intracellular production of gold nanoparticles. And we've written previously about how to use brown algae *Fucusvesiculosus* biomass for bioreduction of Au(III)-Au(0) [10].

This study explored a clean approach for recovering silver from weak solutions by biosynthesising gold nanoparticles utilising aqueous chloruretic ions and dead algae. Algae are an infinite supply of raw materials, and this process demonstrates the tremendous benefit of exploiting them. We are unaware of several reports of biosynthetic processes including metal nanostructures and algae as reducing agents [11]. Finding the best conditions for synthesis and controlling particle shape were the goals of this work, as was investigating a clean and inexpensive way to create nanoparticles utilising algae as a reducing agent [12].

METHODOLOGY

Numerous medical, industrial, and commercial fields make use of silver nanoparticles because of their exceptional optical, electrical, and catalytic characteristics. [13] listed many uses for these compounds, including their anti-inflammatory, anti-viral, antibacterial, and antifungal properties, as well as their coating on implants and surgical tools. The manufacture of silver nanoparticles was effectively accomplished by exploiting *Pithophoraedogoni*, which exhibited maximum absorbance at 445 nm. Using the water-based algae extract, the silver nitrate solution was quickly converted into silver nanoparticles. The use of scanning electron microscopy (SEM) and dynamic light scattering (DLS) technology allowed for the confirmation of the nanoparticle size. The generated silver nanoparticles had a size of 34.03 nm, as previously reported [14, 15]. Making spherical silver nanoparticles of 10 ± 2 nm in diameter requires using an extract from green marine algae, *Caulerpaserrulata*, to decrease the concentration of silver ions. In their 2015 study, [16] found that the red alga *Hypneamusiformis* could biosynthesise silver nanoparticles with a cubic shape and a size range of 2-55.8 nm. They speculated that the presence of peptides might explain the decrease in nanoparticle size [17].

Algae preparation

In summer of 2024, samples of *Chlorella vulgaris*, a kind of freshwater green algae, were taken from Ramappa reservoir in Warangal. After being rinsed with deionised water, the algae were dried in a stove oven set at 60°C and then pulverised using an agate mortar. Sizes of biomass less than half a millimetre were used in the trials [18].

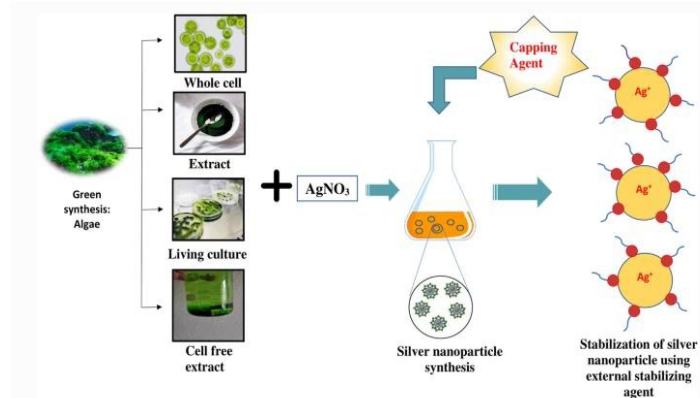


Fig 1. To make it more cost-effective and environmentally friendly, we can employ algae to synthesize AgNPs and then use various capping agents to control the size and stability of the nanoparticles.

Nanoparticle Characterisation

The diameter and ζ -potential of 10-100 μ MgNP in MOPS (10 mM, pH 7.5) were assessed by dynamic light scattering (DLS) between 15 minutes and 4 hours with a Zetasizer (Nano ZS, Malvern Instruments). A UVIKON 930 spectrophotometer was used to measure the UV-vis absorbance of AgNP in MOPS following one hour of exposure. After being exposed to MOPS for 2 hours, the dissolution of AgNP was measured. Using a 3 kDa Millipore centrifugal filter and ultracentrifugation ($145,000 \times g$, 3 hours, CENTRIKON T-2000), the fraction of ultrafiltration was employed to extract dissolved Ag from nanoparticles. In order to analyze the amounts of Ag, the ultrafiltration filtrate and ultracentrifuged supernatant (0.5 mL portion) were acidified.

Chemical Materials

All chemical reagents, including 37% hydrochloric acid, sodium hydroxide flakes, chloroauric acid, and silver nitrate, were purchased from Panreac and used exactly as given.

Mechanism Involved in the Algae-Mediated Biosynthesis of NPs

Heavy metals may be absorbed by algae, which then transform them into more malleable forms. A number of researchers have looked to algae as a potential model organism for the synthesis of nanomaterials, especially nanoparticles of metal. The process of creating NPs starts by incubating a solution of precursor metals with an algae extract [19]. Metal ions can have their charges neutralized by the biological components of algae, which include phytochemicals, pigments, phycobilins, chlorophylls, minerals, lipids, proteins, carbohydrates, fats, and polyunsaturated fatty acids. A three-stage procedure is involved in bio-reduction. During the activation phase, the solution changes color as a result of metal ion reduction and nucleation caused by enzymes secreted by algae cells. Metal nuclei combine throughout development to produce NPs of varying sizes and shapes that are thermodynamically stable. NPs are transformed into their final shape during the final phase of termination. Nanoparticles' physical characteristics are affected by a number of factors, including temperature, pH, time, static conditions, substrate concentration, and agitation. We will be focusing on the process of AgNP biosynthesis by algae, which is comparable to other NP production mechanisms [20–24].

Synthesis of silver nanoparticles

Various aqueous AgNO₃ solutions with an initial concentration of 0.5×10^{-3} were made. In this experiment, the green alga *Chlorella vulgaris* was mixed with 50 cc of a water-based tetrachloroaurate solution and stirred at room temperature. Adding 0.25 g of algae to solutions allowed for the production of silver nanoparticles. For this study, many samples were taken at various points in the reaction time. Filtration using Whatman's 0.2 μ m nylon membrane filters removed the biomass from the reaction mixture.[25]

Transmission electron microscopy (TEM) measurements

Before preparing samples for transmission electron microscopy, carbon-covered copper grids were coated with the product solution and dropped with droplets of the silver nanoparticles synthesized using the algae. The solvent was then allowed to evaporate. JEOL model JEM-2000FX TEM tests were performed with an accelerating voltage of 200 kV. Imaging microscopy with a transmission electron microscope confirmed the presence of clusters of nanoparticles in the sample (Fig. 1).

Aggregates formed among the silver nanoparticles because their shape was not well determined. Nanoparticles that were produced had a spherical form with a diameter of around 30 nm. The samples only contained a little amount of nanoparticles after a lengthy reaction time of more than 2 hours. Characteristics of silver nanoparticles generated by reducing AgNO₃ with the help of green algae were shown by the EDS spectra [26,27].

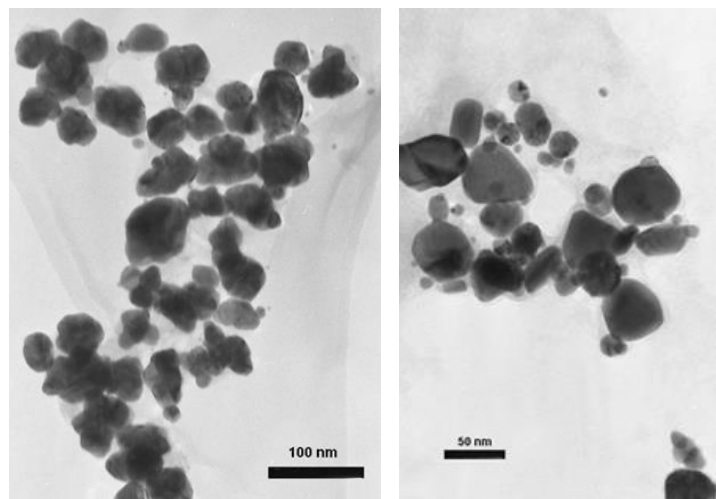


Fig 1. Biosynthesis of silver nanoparticle-TEM Images

CONCLUSION

A less expensive and less environmentally damaging alternative to the conventional physical and chemical processes is the biological manufacture of metallic nanoparticles. Several scholars have looked into the biological capability of algae to create nanoparticles of different sizes and forms in different environments. Stabilized nanoparticles were successfully produced using algal biomolecules as a reducing and capping agent, eliminating the requirement for hazardous chemicals. Pollutants, both organic and inorganic, are destroying our planet at an alarming rate; thus, it is critical that we find ways to reduce our reliance on these harmful substances. If we want to clean up our air, water, and soil of pollutants without hurting the environment, phytotechnology is the way to go. Molecular level knowledge of the process involved in synthesis remains elusive, despite the widespread use of metal salts and their successful bioreduction to their elemental states. There are a number of other types of algal biomass that have yet to be investigated. Hence, more studies are needed to determine the best biological source for the effective synthesis of nanoparticles with lower diameters, along with the specific mechanisms involved.

Applications

In addition to their widespread usage in medicine and pharmaceuticals, nanoparticles like platinum, silver, and gold find widespread use in personal care items that people use on a daily basis, including shampoos, soaps, shoes, cosmetics, toothpaste, and deodorant [28]. Testing for antibacterial action against human pathogens such as *P. mirabilis* and *S. aureus* has also been conducted on silver nanoparticles ranging in size from 5 to 25 nanometres, which were synthesised utilising the marine algae *Caulerparacemose*. According to the study's findings, silver nanoparticles cause cell death by attacking cell membranes, entering bacterial cells, and interfering with respiratory chain cell division [28].

Because of its wide surface area, which allows for the interchange of electrons between electron donors and acceptors, silver nanoparticles produced by the green algae species *Caulerparaserrulata* were also shown to be effective in the catalysis of Congo red (CR) dye [29]. In addition to having antibacterial properties against both gramme positive and gramme negative bacteria, silver nanoparticles made from the freshwater microalgae *Chlorella pyrenoidosa* have been photocatalytically tested against methylene blue dye. This has given rise to the idea that they could be used to treat effluent that contains hazardous dye from chemical processes in industrial sectors [30].

Limitations and Future Prospects

For green NP production, algae are great options because of their abundance of secondary metabolites, which have decreasing and capping effects. Given the relative youth of the industry, commercial scalability is, alas, still out of reach. Possible causes include inefficient algal strain selection, long reaction times (days to weeks), low NP yield, unsatisfactory NP morphological properties, and insufficient optimization of synthesis conditions (such as pH, temperature, contact time, and concentration). It is important to address the issue of process control because NP yields can fluctuate. Moreover, numerous studies are needed on the subject of colloidal stability. Reason being, there has been substantial aggregation in a few instances. The use of algae in NP production has been hindered by a lack of a basic understanding of the synthesis process. Cell survival, yield, and kinetics are thus important challenges that require further investigation before massive photo-bioreactors can be constructed. There is a significant knowledge vacuum on the cultivation and application of algae, which needs to be filled by researchers in addition to studying the physiochemical characteristics of NPs produced by traditional methods. Also, a lot of study has to be done to figure out which biomolecules cause the reduction and NP capping that happens during biosynthesis mediated by algae. Additionally, while specific NPs like silicon, zinc oxide, palladium, and carbon-based NPs have been synthesized from algae, there are numerous other types and quantities that might potentially be investigated in the coming years. We can enhance the properties of algal-mediated NPs for commercial uses by utilizing new upcoming characterization technologies that allow for controlled and comparative synthesis of algal-based Nps.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

"DISCLAIMER

Author(s) hereby certify that NO generative AI tools such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been utilized during authoring or editing of this paper.

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