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Utilization of Algae for the Green Synthesis of Silver Nanoparticles and Their Applications

Sanjay Singh[*], Preeti Maurya, Khushaboo Soni

Department of Botany, Choudhary Mahadeo Prasad Degree College, University of Allahabad, Prayagraj, India

Email address:
cmpsanjay@gmail.com (Sanjay Singh)
[*]Corresponding author

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Abstract: This study aims to provide an overview of silver nanoparticles and their applications. Among the many applications for nanoparticles, nanoparticle synthesis is a particularly appealing research issue. Silver nanoparticle synthesis is an emerging field due to its wide applications in different fields. Silver nanoparticles are manufactured using a variety of processes, including physical, chemical, and biological approaches. Physical and chemical procedures are both expensive and dangerous. As a result, biological procedure is considered cleanest and safest as no toxic chemicals are used in this. The biological procedure includes the use of microbes, algae, and plant extract for the nanoparticle synthesis. Algal-mediated biosynthesis of silver nanoparticles is easy, nontoxic, environmentally friendly, and requires less time. Algae have the high capacity to take metals and reduce metal ions apart from their wider distribution and abundant availability. Algae can help in mass scale production of nanoparticles at a low cost. Several physical factors such as algal extract concentration, the effect of pH, time, and temperature controlled the formation and stabilization of silver nanoparticles. AgNPs are important because of their antimicrobial, antifungal, anticancer, and wound-healing activities. Algal-synthesized AgNPs are increasingly being used in biomedicine. Targeted drug delivery techniques employ silver nanoparticles. The benefit of wound healing by silver nanoparticles includes cytokine release, which inhibits mast cell infiltration and so acts as an anti-inflammatory agent. Nanoparticles maintain electrical and optical features that can be applied to biosensors. The high-quality production of algae-mediated silver nanoparticles will enhance the properties and usefulness of AgNPs for commercial use. Silver nanoparticles boost membrane permeability and generate a hole in *E. coli* bacteria's cell wall. This review highlighted the wide applications of silver nanoparticles in the field of medicines, therapeutics, cosmetics, biosensors, etc. and their different methods of synthesis.

Keywords: Nanoparticles, Synthesis of Silver Nanoparticles, Physical Factors, Anticancer, Antibacterial Activities

1. Introduction

Nanotechnology is an enabling technology that works with things as small as a nanometer. Nanotechnology is predicted to evolve at three levels: materials, devices, and systems. Because of their unique shape-dependent optical, electrical, and chemical [23] characteristics that have potential uses in nanobiotechnology, the synthesis of nanoparticles utilizing biological entities has piqued the interest of many researchers [39]. When compared to bulk silver, nanocrystalline silver particles exhibit a wide range of unusual features (8–12). The resultant silver powders often have particle sizes bigger than one micron.

Silver nanoparticles may be manufactured using a variety of processes, including: -

a) Physical methods
b) Chemical methods
c) Biological methods [31]

Top to bottom and bottom to up are the two approaches. Smaller atoms of molecules combine themselves to make nanoparticles [8] via a bottom-up technique. One of the most frequent ways of producing silver nanoparticles is chemical synthesis. Numerous chemicals and reagents are employed to reduce the silver ions and stabilize the nanoparticles [7, 54]. The catalytic process, sol-gel technique, and Langmuir-Blodgett method, (chemical solution deposition a technique for producing supra molecular assemblies in ultrathin films with a regulated layered structure and crystal parameter) are some of the methods employed in this process components of electrical circuits, displays, detectors, sensors, and wet chemistry. Chemical processes are inexpensive for large-scale production, but they have significant disadvantages, such as pollution from precursor chemicals, the use of toxic solvents, and the generation of hazardous products [23], whereas physical methods have a low production rate, a high production cost, and high energy consumption [10]. Toxic components must be replaced by an ecologically friendly way of generating NPs. To address this, scientists are working on adopting a green synthesis for nanoparticle [14] manufacturing. They are often inexpensive, harmless, and environmentally friendly.

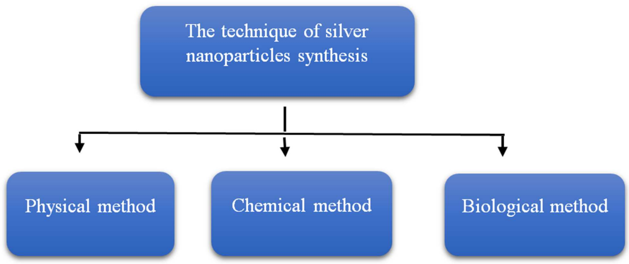

Figure 1. *Diagram showing the technique of silver nanoparticle.*

In light of this, 158 Algae Organisms for Imminent Biotechnology [24] have been created, which involves the synthesis of NP utilizing various biological sources that might naturally adjust the form or size of a crystal with higher quality [14]. For ages, silver-based compounds have been utilized as harmless inorganic antibacterial agents due to their biocidal capabilities in a variety of applications such as wood preservatives, hospital water purification, wound or burn-to-dress, and so on [6]. Recent developments in nanoparticle synthesis have had a significant influence on many scientific fields, and the production of silver nanoparticles has followed [6] suit.

Silver nanoparticles are a significant type of nanomaterial. At the moment, it is mostly utilized as a catalyst or as an antibacterial/antifungal agent. Environmentally friendly synthesis techniques are gaining popularity in chemistry and chemical [6] technology. This tendency stems from several factors, including the need for greener solutions to offset the increased prices and energy needs of physical and chemical processes [6]. As a result, scientists [6] are looking for less expensive synthesis methods.

The green synthesis approach is the choice of the solvent medium (preferably water), an environmentally friendly reducing agent, and nontoxic material for the stabilization of the nanoparticles. Many approaches were investigated, and microorganisms such as bacteria, yeasts, fungi, and algae were used in the biosynthesis of metal nanoparticles [9]. Algal biomass was employed to create metallic nanoparticles, earning algae the nickname "bionanofactories" among biological materials. For the production of silver nanoparticles, a [40] variety of algae, including *Lyngbya majuscule, Spirulina platensis*, and *Chlorella vulgaris*, [4] were employed.

Silver nanoparticles were created using *Ulva fasciata* extract as a reducing agent, and these nanoparticles [14] stopped *Xanthomonas campestris pv. malvacearum* from growing [34].

A more recent area of study that has been given the name "phyconanotechnology" is the manufacture of nanometals by algae. This justifies the potential and advantageous use of algal-mediated synthesized nanoparticles for both the present and the future [14].

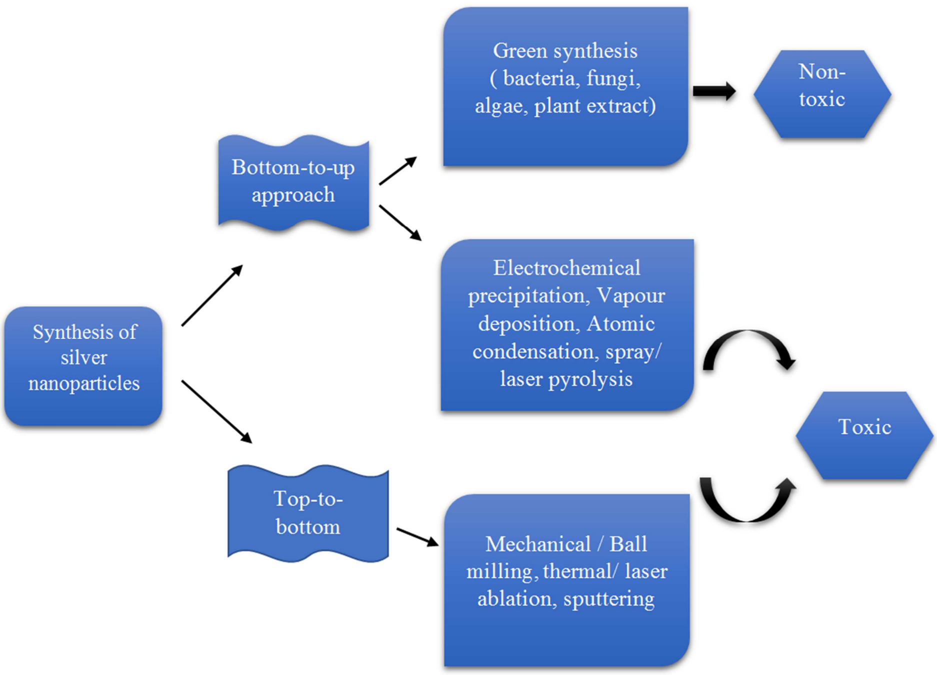

Figure 2. *Various methods for the silver nanoparticles synthesis.*

2. Synthesis of NPs Using Algae (Biosynthesis of AgNPs)

Algae are a suitable and worthwhile source for the production of metallic nanoparticles given their abundance and simplicity of access [11]. The synthesis of nanoparticles using algae can be accomplished in three steps: (a) preparation of algal extract in water or an organic solvent by heating or boiling it for a set period, (b) preparation of molar solutions of ionic metallic compounds, and (c) incubation of algal solutions and molar solutions of ionic metallic compounds under controlled conditions, either with continuous stirring or without stirring [14]. NP production is dose-dependent and also depends on the kind of algae [4] employed. Metal reduction is caused by a range of biomolecules, including polysaccharides, peptides, and pigments. Proteins, via amino groups or cysteine residues, and sulfated polysaccharides [14], stabilize and cap metal nanoparticles in aqueous solutions [42]. The synthesis of nanoparticles using algae requires less time than the other biosynthesizing [14] processes. Several seaweeds, including *Sargassum wightii* and *Fucus vesiculosus*, have been utilized to create silver nanoparticles [1, 10] of various sizes and forms.

AgNPs are manufactured by various algae species, and the size and form of the NPs generated vary. The table below depicts the many algal species.

Table 1. *Algal-mediated biosynthesis of AgNPs, their size, shape, temperature, and references.*

Algae species	Synthesis	Size of NPs	Shape	Temperature	References
Microcoleus sp.	Extracellular	44-79nm	Spherical	RT	Sudha SS, Rajamanickam K, Rengaramanujam J (2013) [14]
Phormidium willei	Extracellular	100-200nm	Spherical	25°C	Ali DM, Sasikala M, Gunasekaran M, Thajuddin N (2011) [1, 7, 54]
Plectonema boryanum	Intracellular & Extracellular	1-5, 1-40, 5-200nm	Spherical & octahedral	25, 60, 100°C	Lengke MF, Fleet ME, Southam G (2007) [7]
Spirulina platensis	Extracellular	~12nm	Spherical	25°C	Mahdieh M, Zolanvari A, Azimee AS [7], Mahdieh M (2012) & Govindaraju K, Basha SK, Kumar VG, Singaravelu G (2008) [7, 54]
Chlamydomonas reinhardtii	Intracellular & Extracellular	5-15nm (in vitro), 5-35nm (in vivo)	Round / rectangular	RT°C	Haider A, Kang I (2014) [13]
Chlorella vulgaris	Intracellular	~10nm	Spherical	28°C	Soleimani, M. and Habibi-Pirkoohi & Ebrahiminezhad A, Bagheri M, Taghizadeh SM, Berenjian A, Ghasemi Y (2016) [7, 54]
Nannochloropsis ocule	Intracellular	~19nm	Spherical	28°C	El-Kassas HY, Ghobrial MG (2017) [7]
Caulerpa racemose	Extracellular	5-25nm	Spherical /triangular	RT	Kathiraven T, Sundaramanickam A, Shanmugam N, Balasubramanian T (2015) [14]
Codium capitatum		~30nm		Room Temperature	Kannan RRR, Stirk WA, Van Staden J (2013) [18, 7, 54]
Ulva fasciata	Extracellular	28-41nm	Spherical	Room Temperature	Rajesh S, Patric Raja D, Rathi JM, Sahayaraj K (2012) [7, 34, 54]
Padina gymnospor		25-40nm	Spherical	30°C	Shiny PJ, Mukherjee A, Chandrasekaran N (2013) [7]
Padina pavonica	Extracellular	45-64nm	Spherical	-	Sahayaraj K, Rajesh S, Rathi JM (2012) [7, 38]
Gelidiella acerosa		22nm	Spherical	Room Temperature	Kumar P, SenthamilSelvi S, Govindaraju M (2013) [21, 17]
Gracilaria dura		6nm	Spherical	25, 60, 100°C	Shukla MK, Singh RP, Reddy CRK, Jha B (2012) [41, 27]
Hypnea musciformis		40-65nm	Spherical	Room Temperature	Roni M, Murugan K, Panneerselvam C, Subramaniam J, Nicoletti M, [36, 27] Madhiyazhagan P, Dinesh D, Suresh U, Khater HF, Wei H, Canale A, Alarfaj AA, Munusamy MA, Higuchi A, Benelli G (2015) [7, 54]

3. Silver Nanoparticle

Silver nanoparticles are the most often employed antibacterial agent against various bacteria, fungi, and viruses [14]. The effectiveness of antimicrobial was shown that the activity of AgNP is size dependent [14], with bigger particles being less effective than smaller ones against several pathogens in both analyses done in vitro and in vivo [14]. Since bacteria are becoming more resistant to antibiotics, AgNPs are now more effective than antibiotics. A hole is made in the cell wall of *E. coli*, by silver nanoparticles. This inhibits cell activity by increasing membrane permeability. According to certain studies, the Ag ions attach to thiol and amino groups in proteins, causing structural disruption. AgNPs are photocatalytic and can produce reactive oxygen species (ROS). Gram-positive and Gram-negative bacteria [32] are both resistant to AgNPs [26].

4. Factors Controlling the Synthesis of Silver Nanoparticles

Physical Factors such as pH, concentration, time, and temperature control the nucleation, formation, and stabilization of NPs [5].

4.1. Effect of Extract Concentration [20]

One of the most critical parameters influencing the production of silver nanoparticles is the concentration of the algal extract [8]. It has been discovered that the concentration of biomass/extract is directly connected to the production of nanoparticles [7, 54]. The impact of *C. serrulata* extract concentration on AgNP production was observed by Aboelfetoh et al. They discovered that by progressively increasing the concentration of the extract (5 to 20%) in 103 M $AgNO_3$, the intensity of SPR [7, 54] rose and a shift towards a lower wavelength occurred (435 nm) [7, 54]. This change occurred as a result of a drop in the mean size of AgNPs [8]. When the concentration was increased to 25%, the SPR intensity decreased owing to nanoparticle aggregation.

4.2. Effect of pH

The change in pH values during the synthesis plays a significant role in controlling the shape, size, and stability of silver nanoparticles [19]. A pH of 7 was the best to ensure the reduction of Ag^+ to Ag^0 during AgNP production, and the greatest abundance of synthesized nanoparticles was obtained at pH 7–9 [53]. *Sargassum longifolium* produces anisotropic AgNPs at lower pH, while monodispersed and small-size particles at higher pH [32]. *R. fontinales* yield maximum AgNPs at pH 9.0. Chromatic change in the reaction mixture and SPR band peak intensity was dependent on pH. The reducing and stabilizing power of *C. serrulata* extract was enhanced at basic pH. With an increase in pH from 6.65 to 9.95, a narrow SPR band at 427 nm was observed along with an increase in absorbance [5].

4.3. Effect of Time

The $AgNO_3$ solution is incubated with microorganisms or their extract for [7, 54] sometime during the biological production of NP. The reaction period or incubation time also influences the manufacturing of silver nanoparticles by algae. Kannan et al. discovered that *Codium capitatum* took around 48 hours [7, 54] to produce nanoparticles from the precursor, but *Chaetomorpha linum* required only 30 minutes. The nanoparticles were spherical and averaged 12 nm in size [35]. *C. serrulata* extract (10%) and Ag+ ions were allowed to interact at room temperature for 8 days [5]. *S. cinereum* converts AgNPs in about 3 hours, while *R. fontinales* takes 72 hours.

4.4. Effect of Temperature

Temperature is important in the synthesis of AgNPs because it accelerates the pace of reaction owing to the quick usage of reactants, resulting in the creation of smaller NPs. The form of nanoparticles can also be affected by temperature. Lengke et al. discovered that the shape of AgNP altered with [7, 54] temperature during its production using the Cyanobacterium *Plectonema boryanum*. With a temperature rise from 27 to 95°C, the less strong SPR band at 440 nm sharpens to 412 nm [5], reducing the overall response time to 1 h. At all of the temperatures between 25 and 100°C, spherical silver nanoparticles were seen; however, AgNP with an octahedral shape was only produced at 100°C. The diameter of *Cystophora moniliformis* is 75 nm when the temperature is below 65°C. Additionally, he asserted that nanoparticle aggregation happens at higher temperatures (85–90°C), resulting in a particle cluster, larger than 2 m being found at 95°C. Another study found that when the temperature was between 60 and 80 degrees Celsius, the creation of AgNPs was efficient.

5. Use of Silver Nanoparticles

They have a major role in the development of novel and effective drugs, catalysts, sensors, and pesticides [3]. Because of their antibacterial, antifungal, anti-cancer, and wound-healing [14] activities, algal-synthesized NPs are increasingly being used in biomedicine.

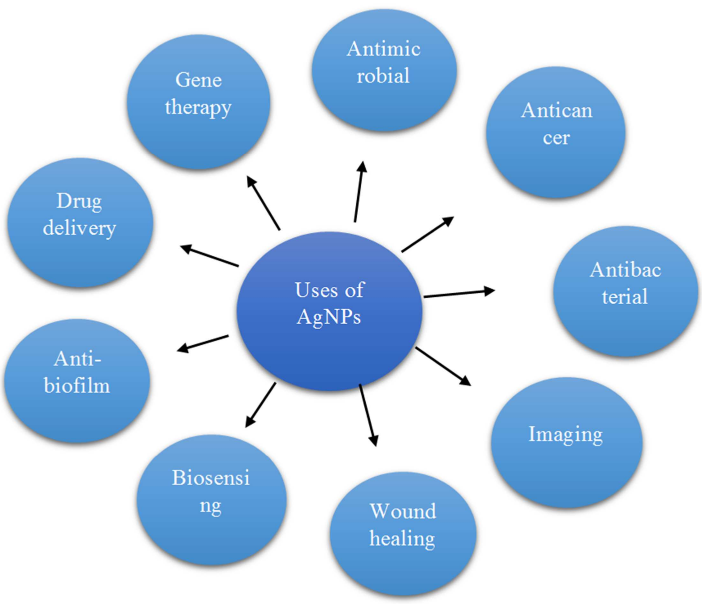

Figure 3. *Diagram showing the different uses of AgNPs.*

5.1. Antibacterial Activity

Algal-synthesized NPs are [14] effective antibacterial agents. The growth of Gram-negative bacteria *E. coli* was suppressed by the synthesis of AgNPs utilizing fresh extract and whole cells of the microalga *Chlorococcum humicola* (ATCC 1105) [14]. Aqueous extract of the diatom Amphora-46 was [14] employed in a recent study for Fucoxanthin, a photosynthetic pigment, which is in charge of the reduction of Ag ions in the light-induced formation of polycrystalline AgNPs [30]. Moreover, the antibacterial efficacy of the produced AgNPs was evaluated against Gram-positive and Gram-negative [24] microorganisms.

Table 2. *Silver nanoparticles show the antibacterial activity.*

Algae	NPs	Size	Shape	Intracellular (IC) or extracellular (EC)	Pathogens	References
Chlorococcum humicola	Ag	4 and 6 nm	Spherical	IC	*E. coli* (ATCC 1105)	Jena J, Pradhan N, Dash BP, Shukla LB, Panda PK (2013) [15, 4].
Amphora-46	Ag	5–70 nm	Spherical	IC		Jena J, Pradhan N, Dash BP, Panda PK, Mishra BK (2015) [14, 16].
Caulerpa racemose	Ag	5–25 nm	Spherical and triangle		*S. aureus* and *P. mirabilis*	Kathiraven T, Sundaramanickam A, Shanmugam N, Balasubramanian T (2015) [14].
Microcoleus sp.	Ag				*P. vulgaris, S. typhi, V. cholera, Streptococcus sp., B. subtilis, S. aureus, E. coli*	Sudha SS, Rajamanickam K, Rengaramanujam J (2013) [14].
Ulva fasciata	Ag	28–41 nm	Spherical	IC	*Xanthomonas campestris pv. malvacearum*	Rajesh S, Raja DP, Rathi JM, Sahayaraj K (2012) [14, 34].
Padina pavonica	Ag	10–72 nm	Spherical	IC	*Fusarium oxysporum f. sp. vas infectum Xanthomonas campestris pv. malvacearum*	Sahayaraj K, Rajesh S, Rathi JM (2012) [43, 12, 38].
Gracilaria dura	Ag	6 nm	Spherical	IC	*B. pumilus* (accession number HQ318731).	Shukla MK, Singh RP, Reddy CRK, Jha B (2012) [12].

A sea alga called *Caulerpa racemose* was used to make AgNPs, which have antibacterial properties against *S. aureus* and *Proteus mirabilis*. The *Microcoleus* species' cellular metabolites are AgNPs were produced using these chemicals, and they improved the antibacterial effects of antibiotics against *Proteus vulgaris, Salmonella typhi, Vibrio cholera, Streptococcus sp., Bacillus subtilis, S. aureus,* and together with *E. coli* [14].

The antibacterial efficacy against Gram-positive and Gram-negative bacteria [16] of the aqueous extract of the red marine alga *Gracilaria corticata* as the reducing agent was [14] investigated. AgNPs derived from *U. fasciata* were created and utilized to *stop Xanthomonas campestris* pv *malvacearum* from growing.

Cotton Fusarium wilts (*Fusarium oxysporum* f. sp. *vasinfectum*) and bacterial leaf blight (*Xanthomonas campestris* pv. *malvacearum*) development was prevented by extracellular production of AgNPs from the thallus broth of marine algae *Padina pavonica* (Linn.) [11]. AgNPs and a nanocomposite made from agar derived from the red alga *Gracilaria dura* were evaluated against *B. pumilus* [14] for their ability to kill bacteria (accession number HQ318731).

5.2. Antifungal Activity

This includes the creation of AgNPs that show antifungal activity against the fungi *Humicola insolens* (MTCC 4520), *Fusarium dimerum* (MTCC 6583), *Mucor indicus* (MTCC 3318), and *Trichoderma reesei* (MTCC 3929) [16]. Against the harmful fungus *Aspergillus fumigatus, Candida albicans,* and *Fusarium* sp., [14] AgNPs are mediated by an algal (*Sargassum longifolium*) cell was established.

5.3. Anticancer Activity

AgNPs produced using *G. corticate* have antioxidant properties. The majority of AgNPs generated using green synthesis are being studied for biomedicine, namely as antibacterial agents or cancer treatments. Recent [21] investigations demonstrated that *Chrysanthemum indicum L.* Or *Acacia leucophloea* extract may be used to produce AgNPs with diameters ranging from 38-72 nm to 17-29 nm, respectively [6]. Both samples exhibited excellent antibacterial characteristics [6].

5.4. Antibiofilm

Nanoparticles can pass through the EPS membrane as well as the membranes of cells. It was found that silver nanoparticles were more plentiful than the others and that they acted as an antibiofilm against both gram-positive and gram-negative bacteria [29].

5.5. Antimicrobial Activity

Because of their ability to overcome antibiotic resistance, AgNPs are commonly employed as antimicrobial agents. Some nanoparticle features, such as a very high aspect ratio in the case of AgNPs, allow them to efficiently interact with other particles, increasing their antibacterial efficacy manyfold (Thakkar et al. 2010) [12, 46].

Silver nanoparticles generated by certain algae have antimicrobial properties. These are as follows:

Table 3. *Different sizes, shape and volume used in the biosynthesis of AgNPs using different algae & their antimicrobial activity with references.*

ALGAE	SIZE OF NP/SHAPE	VOLUME OF NP USED	ANTIMICROBIAL ACTIVITY (Zone of inhibition)	REFERENCES
Padina tetrastromatica	14nm/spherical	30 microlitre, 60 microlitre, 90 micro litre	*Bacillus sp., Pseudomonas sp., Bacillus subtilis, Klebsiella planticola*	Rajeshkumar S, Kannan C, Annadurai G (2012) [7, 33].
Sargassum polycystum	5–7 nm/ spherical	100 microlitre	*Pseudomonas aeruginosa, Klebsiella, Pneumoniae, Escherichia coli, Staphylococcus aureus*	Thangaraju N, Venkatalakshmi RP, Chinnasamy A, Kannaiyan P (2012) [7, 47, 54].
Gracilaria corticata	18–46 nm/ spherical	30 ml	*C. albicans C. glabara*	Kumar P, SenthamilSelvi S, Govindaraju M (2013) [17].
Gelidiella acerosa	22 nm/spherical	50 micro litre	*Humicola insolens, Fusarium dimerum, Mucor indicus, Trichoderma reesei*	Kumar P, SenthamilSelvi S, Govindaraju M (2013) [17].
Enteromorpha flexuosa	2–32 nm/circular		*B. subtilis, B. pumulis, E. faecalis, S. aureus, S. epidermidis, E. coli, S. cerevisiae, C. albicans*	Yousefzadi M, Rahimi Z, Ghafori V (2014) [7, 51].
Sargassum wightii	8–27 nm/ spherical	30 microlitre, 60 microlitre, 90 microlitre	*Staphylococcus aureus, Bacillus rhizoids, E. coli, Pseudomonas aeruginosa*	Govindaraju K, Kiruthiga V, Kumar VG, Singaravelu G (2009) [12, 7, 54].
Turbinaria conoides	2–17 nm/ spherical	50 ml	*Salmonella, E. coli, S. liquefaciens, A. hydrophila*	Vijayan SR, Santhiyagu P, Singamuthu M, Kumari Ahila N, Jayaraman R, Ethiraj K (2014) [50, 7, 54].
Ulva fasciata	50 nm/spherical	20 microlitre	*C. albicans, C. glabrata*	Lashgarian H, Karkhane M, Alhameedawi A, Marzban A (2021) [7, 22, 54].

5.6. Biosensing

Nanoparticles maintain electrical and optical features that can be applied to biosensors. Selenium (Se) nanomaterial crystals have a high surface-to-volume ratio, are biocompatible, and have good adhering and electro-catalytic activity for H_2O_2 reduction [4]. NPs are used for a variety of purposes. As a result, nanoparticles (NPs) have served as a new biosensor with great sensitivity, delivering non-hazardous intent to environmental quality and medicine liberation [4].

Table 4. *Different types of Silver NPs used in pollutant detection with their references.*

Type of silver nanoparticles	Pollutant detected	Detectable concentration	References
Riboflavin-stabilized AgNPs	Hg^{2+}	5nm	Roy B, Bairi P, Nandi AK (2011) [37, 7].
1-Dodecanethiol (C12h25sh)-capped silver nanoprisms	Hg (II)	10- 500 nm	Chen L, Fu X, Lu W, Chen L (2013). [6]
Starch-coated AgNPs	Hg^{2+}	0.9–12.5 μg L^{-1}& 25–500 μg L^{-1}	Vasileva P, Alexandrova T, Karadjova I (2017) [48].
2-Aminopyrimidine-4,6-diol-capped silver nanoparticles (Apd-AgNps)	Hg^{2+}	0–65 μm	Prasad KS, Shruthi G, Shivamallu C (2018). [29]
Citrate (Cit) And L-cysteine (L-Cys)-capped AgNPs	Hg^{2+}	1–10 Ppm	Prosposito P, Burratti L, Bellingeri A, Protano G, Faleri C, Corsi I, Battocchio C, Iucci G, Tortora L, Secchi V, Franchi S, Venditti I (2019). [30]
Glutathione-stabilized silver nanoparticles	Ni^{2+}	> 25 nm	Li H, Cui Z, Han C (2009). [25]
Casein peptide-capped AgNPs	Cu^{2+}	0.08–1.44 μm	Ghodake GS, Shinde SK, Saratale RG, Kadam AA, Saratale GD, Syed A, Ameen F, Kim DY (2018). [45]
Chitosan-capped silver nanoparticles (Chit-AgNPs)	Fe^{3+}	> 0.53 μm	Tashkhourian J, Sheydaei O (2017). [45]
Starch-coated silver nanoparticles	Fe^{3+}	0.7–7 mg/l	Vasileva P, Dobrev S, Karadjova I (2019) [49].
L-Tyrosine-stabilized silver nanoparticles	Mn (II)	1–10 μm	Annadhasan M, Muthukumarasamyvel T, Sankar Babu VR, Rajendiran N (2014) [2].
Tartaric acid-capped silver nanoparticles	Cr (III) & Cr (VI)	5–100 μg/l Cr (III) & 10–100 μg/l Cr (VI) [7, 54]	Shrivas K, Sahu S, Patra GK, Jaiswal NK, Shankar R (2016). [38]

5.7. Drug Delivery System

Targeted drug delivery techniques employ silver nanoparticles. The NPs' small size allows them to easily enter the tissue and ensure optimal medication delivery. NPs have been extensively studied as a medication delivery carrier throughout the last [36] decade. Silver nanoparticles have become more and more common in drug delivery systems due to their tiny size, capacity to pass the blood-brain barrier, and thin epithelial [4] junctions.

5.8. Wound Healing

Wound healing is a difficult and time-consuming [7, 54] procedure. Age, size, depth of the wound [8], medicine, nutritional state, and other extrinsic and internal variables all influence the process of healing. Wound treatment is critical because infection at the site of damage increases, which can lead to a variety of problems. Antiseptics, topical antibiotics, granulation tissue suppressing agents, herbal therapies, enzyme therapy, and other tropical [7, 54] medicines are among the pharmaceuticals used for wound care and healing (vitamin E, scarlet oil). AgNPs might be a great alternative to traditional treatments. They have modest system toxicity and are effective against multidrug-resistant bacteria. The benefits of silver nanoparticles include reduced cytokine release, which inhibits mast cell infiltration and so acts as an anti-inflammatory agent [52].

The Special Issue also includes a review of micro- and nano emulsions, which covers the theory and methodology in their creation, as well as innovative applications in entomology [3] and parasitology. A growing number of recent articles have highlighted the significant benefits of using green micro- and nanoemulsions to improve the effectiveness and stability of chosen bioactive chemicals of natural origin [3]. Micro- and nanoemulsions of selected natural products have been successfully proposed for the management of public health parasites and vectors (e.g., mosquitoes and ticks), as well as the control of insect and mite species of agricultural importance, as well as the constraints arising from the use of green micro- and nanoemulsions to promote their commercial development for various biological and biomedical purposes [3].

6. Prospects

This needs to be done in conjunction with research aimed at enhancing large-scale synthesis and the economic viability of the [3] suggested procedures, as well as ecotoxicology insights to comprehend the long-term stability and effects of green nanomaterials on both human health and the environment [28, 44].

7. Conclusion

In the developing era of nanotechnology, nanoparticles have become a prominent platform for a diverse range of biological applications in a reliable and sustainable way instead of chemical and physical methods using toxic chemicals and high temperatures that are not only hazardous to the environment and costly too [4]. The toxicity of NPs of the eukaryotic cell is a legitimate concern and remains uncharacterized. In recent years, the vast spectrum of AgNPs used in medicine, cosmetics, biosensors, therapies, and other fields has prompted the development of innovative green production techniques. This review article emphasizes the numerous uses for silver nanoparticles, pointing out that the most widely used way of producing and extracting silver nanoparticles is through the synthesis of algae. A novel, the developing method enables the controlled and high-quality production of algae-mediated nanoparticles (NPs), which enhances the properties and usefulness of these NPs for commercial use.

Authors' Contributions

Conceptualization, Sanjay Singh; data curation, Preeti Maurya; writing- draft preparation, Preeti Maurya, writing-review and editing, Sanjay Singh. All authors have read and agreed to the published version of the manuscript.

Data Availability

Data will be made available on reasonable request.

Conflict of Interests

The authors declare that they have no competing interests.

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