Green synthesis of silver nanoparticles: a review of the methods and Antioxidant properties of nanoparticles

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ABSTRACT

Silver nanoparticles (AgNPs) are well-known for their significant antioxidant properties due to their ability to scavenge and neutralize free radicals and reactive oxygen species (ROS). This characteristic has led to their widespread application in cosmetic, hygienic, and pharmaceutical products. Various synthesis approaches exist for producing silver nanoparticles, broadly categorized into top-down and bottom-up methods. The top-down approaches include mechanical activation, lithography, and other physical methods, whereas bottom-up approaches encompass hydrothermal synthesis, redox reactions, sol-gel processes, and green synthesis techniques. Among these, green synthesis has gained considerable attention because of its environmental friendliness, cost-effectiveness and sustainability. Green synthesis utilizes natural sources such as plants, algae, fungi, and bacteria as reducing and stabilizing agents. This study aims to identify the most suitable green synthesis method for producing silver nanoparticles with potent antioxidant activity. The results indicate that silver nanoparticles, while capable of generating free radicals and interacting with cellular membranes, can also penetrate cells and induce reactive oxygen species (ROS) production. This intracellular ROS generation may lead to apoptosis (programmed cell death), membrane damage and enzyme inhibition. The antioxidant activity of green-synthesized silver nanoparticles is primarily evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. Comparative analyses reveal that silver nanoparticles synthesized using algae exhibit smaller particle sizes, while those synthesized with algae and plant extracts demonstrate higher antioxidant activity compared to other biological mediators.

KEYWORDS

Silver nanoparticles, antioxidant properties, plant extracts, microorganism, green synthesis

1. Introduction

Metal nanoparticles are generally synthesized using two main approaches: the top-down and the bottom-up methods. In the top-down approach, particle size is reduced until it reaches below 100 nm. This method typically yields a higher volume of nanoparticles; however, it comes with limitations such as lack of precise control over the size and shape of the nanoparticles, as well as high operational costs. In contrast, the bottom-up approach involves the assembly and organization of smaller units into larger and more complex structures. This method is generally more time, energy, and cost-efficient compared to the top-down approach. Due to the advantages and disadvantages of each approach, numerous studies have focused on nanoparticle synthesis based on the bottom-up method [1,2]. Examples of top-down methods include electron beam irradiation, laser ablation, mechanical activation, lithography, electrochemical processes, and others [3,4]. In the bottom-up approach, smaller precursor structures form larger and more complex ones. This method typically uses organic and inorganic reducing agents. Some of the commonly used bottom-up techniques include chemical methods such as hydrothermal synthesis, sol-gel, redox reactions, chemical precipitation, and green synthesis [3–5]. Green (biogenic) synthesis involves the use of plant extracts or various microorganisms such as algae, fungi, yeasts, bacteria, and viruses [6–8]. One of the most important metallic nanoparticles is silver nanoparticles, which, due to their unique physicochemical properties, have extensive applications across various industries including medicine, packaging, water purification, and biosensors [3,7]. Investigating the antioxidant properties of silver nanoparticles synthesized via green methods is important due to the extensive applications of the resulting nanoparticles in the fields of medicine and pharmaceuticals.

The present study aims to evaluate and compare the efficiency and antioxidant potential of silver nanoparticles synthesized through green methods (using plant extracts, algae, fungi, and bacteria). To this end, the antioxidant properties of silver nanoparticles, methods for evaluating antioxidant activity, and the mechanisms of their activity will be discussed. Subsequently, studies involving the synthesis of silver nanoparticles using plant, bacterial, fungal, and algal extracts will be reviewed. Furthermore, the relationship between particle size and antioxidant activity of silver nanoparticles, comparison of antioxidant properties of silver nanoparticles with other metal nanoparticles, the effect of nanoparticle stability, the role of phenolic compounds in synthesis, the antioxidant capacity of silver nanoparticles, and the existing research gaps will be explored.

2. Mediators for silver nanoparticle synthesis

As previously mentioned, green synthesis encompasses various methods or pathways, which primarily differ based on the mediators used. In green synthesis, the antioxidant, antifungal, and antibacterial properties of silver nanoparticles are typically examined [9]. Plant extracts contain numerous bioactive compounds such as alkaloids, flavonoids, terpenoids, tannins, saccharides, phenols, vitamins, as well as various enzymes, amino acids, and proteins. Due to the presence of active biomolecules in plant extracts, the synthesis of silver nanoparticles using plants is generally more stable and straightforward. In recent years, numerous studies have been conducted on the green synthesis of silver nanoparticles using different parts of plants, including fruits, seeds, roots, flowers, stems, leaves, bark, and others [10]. Bacterial synthesis is a biosynthetic method in which bacteria produce nanoparticles through their metabolic processes [11]. Compounds derived from algal enzymes and silver ions can function as antioxidants through electron transfer. The antioxidant capacity of silver nanoparticles synthesized using algae is attributed to the enzymatic components present in the algae. Studies have shown that the algal culture medium, the type of algae, and the compounds present in the algae influence the size and antioxidant properties of the nanoparticles [12]. Fungi used in related studies have demonstrated high biodiversity and significant potential for synthesizing nanoparticles with strong antioxidant activity. Due to the presence of secondary metabolites and specific enzymes, fungi can act as biological catalysts in the nanoparticle synthesis process [13].

The sizes of silver nanoparticles synthesized using plant, bacterial, fungal, and algal extracts are shown in Figure 1. It can be observed that the antioxidant activity ranges of silver nanoparticles synthesized with plant, algal, bacterial, and fungal extracts fall within approximately 55–100, 50–95, 10–85, and 30–95, respectively. According to Figure 1, silver nanoparticles synthesized using plant and algal extracts exhibit higher antioxidant activity compared to those synthesized using bacteria and fungi. Additionally, the size range and antioxidant activity of silver nanoparticles synthesized with plant extracts appear to be closely aligned. The size of silver nanoparticles depends on the components present in the reducing and stabilizing agents. An increase in the concentration of compounds such as polymers may lead to particle growth and thus result in larger nanoparticle sizes. The spherical shape of silver nanoparticles is influenced by the chemical properties and structure of silver. Furthermore, the spherical morphology increases the surface area of the nanoparticles for interaction with other substances, which can enhance their performance and applications in various fields such as catalysis, sensing, electronics, and medicine. On the other hand, the antioxidant activity of silver nanoparticles is affected by conditions such as pH and temperature. It has been shown that antioxidant activity increases at lower pH (acidic conditions) and lower temperatures. Research related to the green synthesis of silver nanoparticles using plant and algal extracts is more prevalent compared to bacterial and fungal methods. This can be attributed to the availability and ease of cultivation of plants and algae compared to fungi and bacteria. The synthesis process using plant and algal extracts requires the shortest time, whereas synthesis using bacteria and fungi requires longer durations and strictly impurity-free environments. Notably, silver nanoparticles synthesized using algae tend to have smaller sizes compared to those produced using other mediators. The antioxidant properties of silver nanoparticles synthesized with algae and plant extracts are greater than those synthesized with bacterial and fungal extracts.

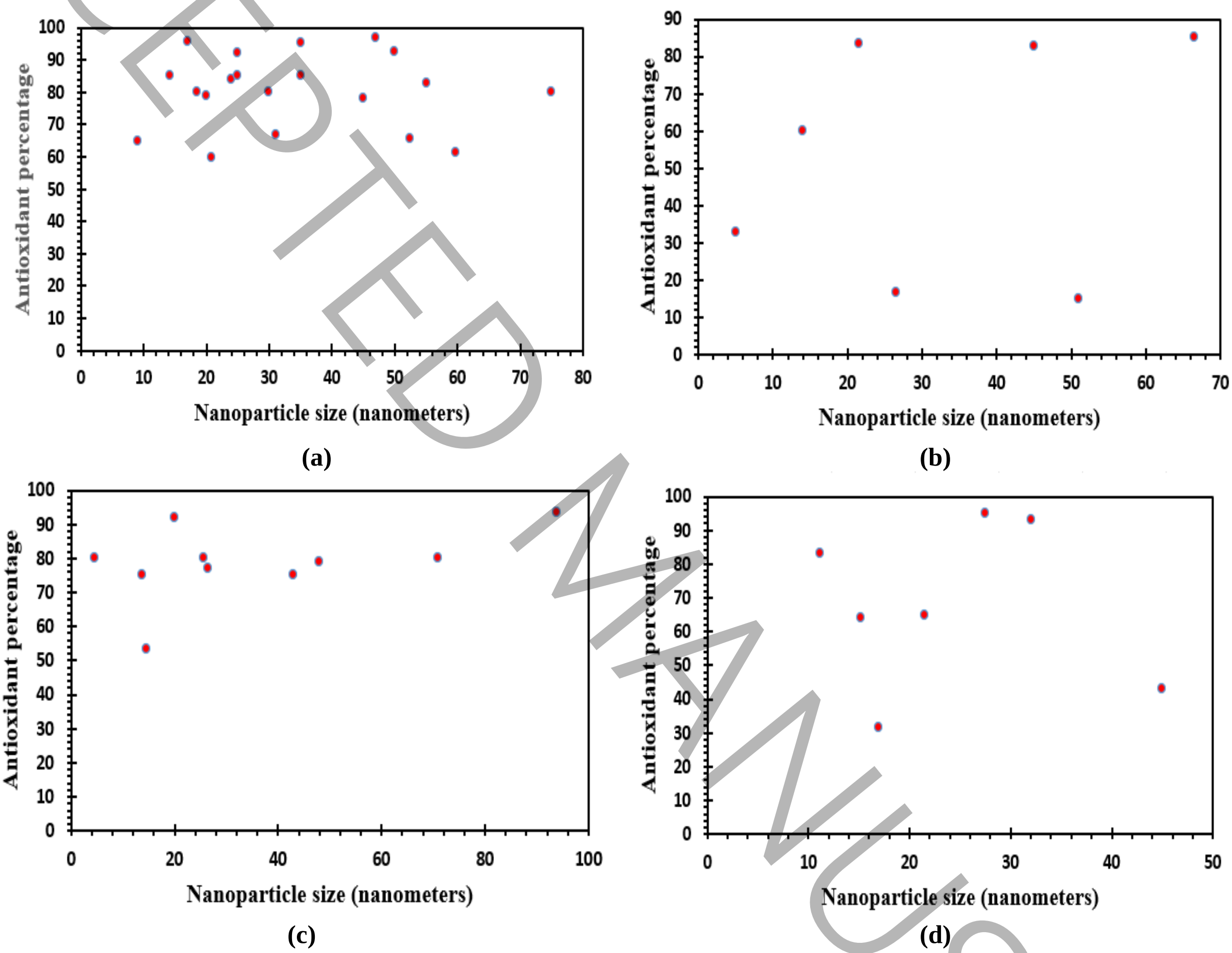

Figure 1. The effect of nanoparticle size synthesized with algae, fungi, bacteria, and plant extracts on the antioxidant activity of silver nanoparticles. (A: Bacteria, B: Plant extract, C: Algae, D: Fungi)

3. Conclusion

- Using plant, fungal, algal, and bacterial extracts for the synthesis of silver nanoparticles offers an eco-friendly and cost-effective alternative to conventional chemical methods, minimizing environmental hazards.
- Phytochemicals such as flavonoids, phenolics, and terpenoids play a vital role in reducing silver ions, stabilizing nanoparticles, and enhancing their antioxidant activity.
- Silver nanoparticles synthesized from plant and algal extracts demonstrate superior antioxidant performance compared to those produced using bacterial or fungal systems, due to the richer and more diverse chemical content of plant-based sources.

- Difficulties in controlling nanoparticle size and shape, incomplete understanding of biological synthesis mechanisms, and limitations in scaling up for industrial production remain key obstacles.

- Future studies should focus on exploring novel biological sources, optimizing synthesis conditions, gaining deeper insights into biosynthetic pathways, and improving the stability and functional properties of the nanoparticles.

- Green-synthesized silver nanoparticles exhibit significant potential in fields such as water purification, food packaging, medical applications, and biosensing technologies, offering a promising outlook for sustainable nanotechnology.

4. References

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