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Review of the Synthesis of Ag++ Nanoparticles via Green Chemistry Using Garlic Extract for Enhanced Antifungal Activity

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Abstract
The synthesis of silver (Ag++) nanoparticles (NPs) through green chemistry approaches has garnered significant attention due to its eco-friendly and sustainable nature. This review focuses on the utilization of garlic extract as a reducing and stabilizing agent in the synthesis of Ag++ nanoparticles. Garlic, rich in sulfur-containing compounds, offers a biocompatible alternative to conventional chemical methods, minimizing environmental impact and potential toxicity. The synthesized nanoparticles exhibit unique physicochemical properties, contributing to their enhanced antifungal activity. This review examines the mechanisms underlying the synthesis process, the characterization techniques employed, and the antifungal efficacy of the produced nanoparticles against various fungal pathogens. Furthermore, it highlights the potential applications and benefits of using garlic extract in nanoparticle synthesis, such as cost-effectiveness, scalability, and the reduction of harmful by-products. The integration of green chemistry principles in nanoparticle synthesis not only aligns with sustainable development goals but also opens new avenues for biomedical and environmental applications. This review aims to provide a comprehensive understanding of the advancements and challenges in this emerging field.

Introduction
The synthesis of nanoparticles has revolutionized various fields, including medicine, electronics, and environmental science, due to their unique physical and chemical properties. Among the different types of nanoparticles, silver (Ag++) nanoparticles have gained significant attention for their broad-spectrum antimicrobial properties. Traditionally, the synthesis of Ag++ nanoparticles involves chemical methods that often require toxic reagents and generate hazardous by-products, posing environmental and health risks. To address these concerns, green chemistry approaches have emerged as sustainable alternatives, emphasizing the use of eco-friendly and biocompatible materials.

One promising green synthesis method involves the use of natural plant extracts as reducing and stabilizing agents. Garlic (Allium sativum) extract, in particular, has shown considerable potential in the synthesis of Ag++ nanoparticles. Garlic is rich in sulfur-containing compounds, such as allicin, which not only reduce silver ions to form nanoparticles but also stabilize them, preventing agglomeration. Additionally, the antimicrobial properties of garlic further enhance the efficacy of the synthesized nanoparticles, making them highly effective against fungal pathogens.This review focuses on the synthesis of Ag++ nanoparticles using garlic extract and examines their enhanced antifungal activity. The integration of green chemistry principles in this process not only aligns with sustainable development goals but also reduces the environmental footprint associated with nanoparticle synthesis. By utilizing garlic extract, the synthesis process becomes more cost-effective and scalable, while also minimizing the production of harmful by-products.

Need of the Study

The increasing prevalence of fungal infections, coupled with the growing resistance to conventional antifungal drugs, has necessitated the development of novel and effective treatment alternatives. Nanotechnology, particularly the synthesis of nanoparticles, offers promising solutions due to the unique properties of nanoparticles, such as their large surface area and enhanced reactivity. Among these, silver nanoparticles (Ag++) have garnered significant attention for their potent antimicrobial properties. However, traditional methods of synthesizing silver nanoparticles often involve toxic chemicals and harsh conditions, posing environmental and health hazards.In this context, green chemistry provides a sustainable approach to nanoparticle synthesis by using natural extracts as reducing and stabilizing agents. Garlic extract, known for its rich bioactive compounds and medicinal properties, presents an eco-friendly alternative for the synthesis of Ag++ nanoparticles. This study aims to explore the potential of garlic extract in the green synthesis of Ag++ nanoparticles and evaluate their antifungal activity. Understanding the efficacy and mechanisms of these biogenically synthesized nanoparticles can lead to the development of safer, more effective antifungal treatments, addressing both medical and environmental concerns associated with traditional synthesis methods.

Green synthesis of silver nanoparticles using garlic extract

The green synthesis of silver nanoparticles (Ag++) using garlic extract represents an innovative and environmentally friendly approach to nanoparticle production. Garlic (Allium sativum) is renowned for its rich content of bioactive compounds, such as allicin, which possess strong reducing and stabilizing properties. In this green synthesis process, garlic extract acts as a natural reducing agent, converting silver ions (Ag+) into silver nanoparticles (Ag++). This method bypasses the need for toxic chemicals and harsh reaction conditions typically used in conventional nanoparticle synthesis.

The procedure involves mixing an aqueous solution of silver nitrate with garlic extract, leading to the rapid formation of Ag++ nanoparticles. The process is not only simple and cost-effective but also yields nanoparticles with excellent stability and enhanced antimicrobial properties. The biogenic Ag++ nanoparticles produced through this method exhibit significant antifungal activity, making them suitable for medical applications, particularly in combating drug-resistant fungal infections.This green synthesis approach aligns with the principles of sustainable chemistry, minimizing environmental impact while harnessing the medicinal properties of garlic. It offers a promising pathway for developing safe, effective, and eco-friendly antimicrobial agents, highlighting the potential of integrating traditional natural resources with modern nanotechnology.

Literature Review

Abd-Elsalam, K. A., et al (2019). Nanobiofungicides represent an innovative approach in the field of fungal control, merging nanotechnology with biological fungicides to enhance efficacy and environmental safety. Current concepts involve utilizing nanoparticles to deliver antifungal agents more efficiently, improving their stability, bioavailability, and targeted action against fungal pathogens. These nanocarriers can be designed from various materials, including metals, polymers, and lipids, each offering unique advantages such as controlled release and increased solubility of bioactive compounds. Presently, nanobiofungicides are being explored for their ability to overcome the limitations of conventional fungicides, such as rapid degradation, poor penetration, and the development of resistance. For instance, encapsulating natural antifungal agents like essential oils in nanoparticles can protect them from environmental degradation and enhance their effectiveness at lower doses. This targeted delivery not only increases the potency against specific fungal pathogens but also reduces the impact on non-target organisms and the environment. Future perspectives of nanobiofungicides are promising, with potential advancements including the development of multifunctional nanocarriers that can simultaneously deliver multiple bioactive agents, monitor fungal infections, and release fungicides in response to specific triggers. Research is also focusing on the use of biodegradable and biocompatible materials to ensure safety for humans and ecosystems. In summary, nanobiofungicides offer a cutting-edge solution for fungal control, combining the precision of nanotechnology with the efficacy of biological agents. As research progresses, they hold the potential to revolutionize agricultural practices and contribute to sustainable and eco-friendly crop protection strategies.

Dikshit, P. K., Kumar, et al (2021). Green synthesis of metallic nanoparticles is a sustainable and eco-friendly approach that utilizes biological entities such as plants, bacteria, fungi, and algae to produce nanoparticles. Unlike traditional chemical and physical methods, which often involve toxic solvents, high energy consumption, and harmful by-products, green synthesis leverages natural reducing and stabilizing agents found in biological systems. In this method, plant extracts rich in phytochemicals like flavonoids, terpenoids, and phenolic acids are commonly used to reduce metal ions into nanoparticles. These natural compounds not only facilitate the reduction process but also cap the nanoparticles, preventing aggregation and providing stability. Similarly, microorganisms such as bacteria and fungi secrete enzymes and other biomolecules that can reduce metal ions and stabilize the resulting nanoparticles.Green synthesis of metallic nanoparticles offers several advantages, including simplicity, cost-effectiveness, and environmental compatibility. It produces nanoparticles with controlled size and shape, which are crucial for various applications in medicine, electronics, and environmental remediation. For example, silver nanoparticles synthesized using plant extracts have shown excellent antimicrobial properties, making them valuable in medical applications and water treatment. Furthermore, this approach aligns with the principles of green chemistry, minimizing hazardous substances and promoting the use of renewable resources. As research advances, green synthesis is expected to play a pivotal role in the large-scale production of metallic nanoparticles, contributing to the development of sustainable nanotechnology and reducing the environmental impact of nanomaterial manufacturing.

Rizwana, H., Bokahri, et al (2021). Silver nanoparticles (AgNPs) synthesized from aqueous extracts of mace-arils of Myristica fragrans exhibit promising antifungal, antibacterial, and cytotoxic activities, highlighting their potential in biomedical and environmental applications. The mace-arils, the red lacy covering of nutmeg seeds, are rich in bioactive compounds that act as natural reducing and stabilizing agents in the green synthesis of AgNPs. The antifungal activity of these AgNPs is significant against a range of pathogenic fungi, effectively inhibiting their growth by disrupting cell membranes and interfering with essential metabolic processes. This property is particularly valuable in treating fungal infections in plants and humans, offering a natural and effective alternative to synthetic fungicides. In antibacterial applications, the AgNPs demonstrate broad-spectrum efficacy against both Gram-positive and Gram-negative bacteria. They achieve this by generating reactive oxygen species (ROS) and releasing silver ions, which damage bacterial cell walls, proteins, and DNA.

Ali, U. (2020). The doctoral dissertation titled "Green Synthesis, Characterization & Therapeutic Evaluation of ZnO Nanoparticles Prepared Using Extract of Nigella sativa Seeds" from Capital University explores an innovative, eco-friendly approach to nanoparticle synthesis. The research leverages the rich phytochemical composition of Nigella sativa seeds, known for their antioxidant and medicinal properties, to synthesize zinc oxide (ZnO) nanoparticles. The green synthesis method involves using aqueous extracts of Nigella sativa seeds as both reducing and stabilizing agents, avoiding harmful chemicals and high-energy processes typical of conventional nanoparticle synthesis. The resulting ZnO nanoparticles are characterized using various techniques such as UV-Vis spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier-transform infrared spectroscopy (FTIR). These techniques confirm the formation of ZnO nanoparticles, providing insights into their size, morphology, crystalline structure, and surface properties.

EPHRAIM, J. W. (2023). The fungicidal evaluation of Rhizophora racemosa and Ocimumgratissimum extracts, along with green synthesized silver nanoparticles (AgNPs), against mycotoxigenic fungi presents a promising approach to controlling harmful fungal pathogens. This study focuses on leveraging the bioactive compounds found in these plant extracts and the potent antimicrobial properties of silver nanoparticles to inhibit the growth and activity of mycotoxigenic fungi. Rhizophora racemosa, commonly known as the red mangrove, and Ocimumgratissimum, known as African basil, are both rich in secondary metabolites such as phenolics, flavonoids, and essential oils. These compounds have demonstrated significant antifungal properties. In the green synthesis process, aqueous extracts from these plants are used to reduce silver ions to AgNPs, providing a sustainable and eco-friendly method of nanoparticle production. The synthesis is characterized by techniques like UV-Vis spectroscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM) to confirm the formation and properties of the nanoparticles.

Ali, U. (2020). The doctoral dissertation titled "Green Synthesis, Characterization & Therapeutic Evaluation of ZnO Nanoparticles Prepared Using Extract of Nigella sativa Seeds" from Capital University investigates an eco-friendly approach to synthesizing zinc oxide (ZnO) nanoparticles utilizing the bioactive components of Nigella sativa seeds. Known for their rich antioxidant and medicinal properties, Nigella sativa seeds serve as a natural source for reducing and stabilizing agents in the nanoparticle synthesis process. The green synthesis method employed in this research avoids harmful chemicals and high-energy procedures, making it a sustainable alternative to traditional methods. The ZnO nanoparticles synthesized are characterized using a range of techniques, including UV-Vis spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier-transform infrared spectroscopy (FTIR). These techniques confirm the successful formation of ZnO nanoparticles and provide detailed insights into their size, shape, crystalline structure, and surface properties. The dissertation also delves into the therapeutic evaluation of the synthesized ZnO nanoparticles. In vitro studies reveal significant antimicrobial activity against various bacterial and fungal pathogens, indicating their potential as effective antibacterial and antifungal agents. Furthermore, the cytotoxic effects on cancer cell lines suggest possible applications in cancer therapy, highlighting the dual therapeutic potential of these nanoparticles.

Moodley, J. S., Krishna, et al (2020). Green synthesis of metal nanoparticles for antimicrobial activity is a cutting-edge approach that combines the principles of green chemistry with nanotechnology to produce environmentally friendly and effective antimicrobial agents. This method utilizes natural reducing and stabilizing agents found in biological sources such as plant extracts, bacteria, fungi, and algae to synthesize nanoparticles of metals like silver, gold, zinc, and copper. These bio-reducing agents not only facilitate the reduction of metal ions but also stabilize the nanoparticles, preventing aggregation and enhancing their antimicrobial properties. The plant extracts used in green synthesis are rich in phytochemicals like flavonoids, terpenoids, and phenolic acids, which act as natural capping agents. These bioactive compounds endow the nanoparticles with enhanced antimicrobial properties by disrupting the cell membranes of pathogens, generating reactive oxygen species (ROS), and binding to microbial DNA, thereby inhibiting their growth and proliferation.

Rabiee, N., Bagherzadeh, et al (2020). High gravity-assisted green synthesis of ZnO nanoparticles using Allium ursinum (wild garlic) is an innovative approach that enhances the efficiency and eco-friendliness of nanoparticle production. This method leverages high gravity conditions to accelerate the reaction rates and improve the quality of the synthesized nanoparticles. Allium ursinum, known for its rich content of bioactive compounds like flavonoids, phenolic acids, and sulfur-containing compounds, serves as a natural reducing and stabilizing agent. In this process, extracts from Allium ursinum are used to reduce zinc ions to ZnO nanoparticles under high gravity conditions, typically achieved using a rotating packed bed reactor or similar high-shear environment. The high gravity environment promotes better mixing and increased mass transfer rates, leading to more uniform and smaller-sized nanoparticles with enhanced properties. The ZnO nanoparticles synthesized through this method exhibit significant antimicrobial and antioxidant activities, making them suitable for various biomedical and environmental applications.

Paul, A., & Roychoudhury, A. (2021). Repurposing the antimicrobial activity of biosynthesized silver nanoparticles (AgNPs) to combat phytopathogens represents a promising "go green" approach to plant protection. Utilizing green synthesis methods, these nanoparticles are produced using natural reducing agents derived from plants, bacteria, fungi, or algae, thereby avoiding harmful chemicals and minimizing environmental impact. The bioactive compounds in these natural sources, such as flavonoids, terpenoids, and phenolic acids, not only facilitate the reduction of silver ions but also stabilize the AgNPs, enhancing their antimicrobial properties.The antimicrobial efficacy of biosynthesized AgNPs against phytopathogens offers a sustainable alternative to traditional chemical pesticides, which often pose risks to the environment and human health. These nanoparticles can effectively inhibit a broad spectrum of plant pathogens, including bacteria, fungi, and viruses, by disrupting their cell membranes, generating reactive oxygen species (ROS), and binding to microbial DNA, thereby preventing their growth and proliferation. In agricultural applications, biosynthesized AgNPs can be employed as foliar sprays, soil treatments, or coatings for seeds and plant surfaces to protect crops from infections.

Zacharia, S. (2023). Biorational approaches for managing Purple Blotch disease of garlic (Allium sativum L.), caused by the fungus Alternaria porri (Ellis) Cif., offer sustainable and environmentally friendly alternatives to traditional chemical treatments. Purple Blotch is a significant disease affecting garlic crops, leading to reduced yield and quality. Biorational strategies aim to control this pathogen through methods that are non-toxic to humans, animals, and beneficial organisms, and that minimize environmental impact. One effective biorational approach involves the use of biological control agents, such as beneficial fungi and bacteria, which antagonize A. porri through mechanisms like competition, parasitism, and the production of antifungal metabolites. For example, Trichoderma species are known to inhibit the growth of A. porri by outcompeting it for nutrients and space, as well as by secreting enzymes that degrade fungal cell walls.

Research Problem

The rising incidence of fungal infections poses a significant challenge to public health, exacerbated by the increasing resistance of fungi to conventional antifungal agents. This resistance diminishes the efficacy of standard treatments, leading to prolonged infections and increased healthcare costs. Traditional synthesis methods of silver nanoparticles (Ag++) involve hazardous chemicals and conditions, raising environmental and health concerns. As a result, there is a critical need to develop alternative methods for synthesizing silver nanoparticles that are both effective against resistant fungal strains and environmentally sustainable.This study addresses the research problem by exploring the use of garlic extract as a green chemistry approach to synthesize Ag++ nanoparticles. Garlic extract, rich in bioactive compounds, offers a natural and eco-friendly reducing and stabilizing agent for nanoparticle synthesis. The key research questions include: How effective is garlic extract in synthesizing Ag++ nanoparticles? What are the antifungal properties of these biogenically synthesized nanoparticles? By investigating these aspects, the study aims to provide a sustainable solution to the dual challenges of fungal resistance and environmentally harmful synthesis processes, contributing to the development of safer and more effective antifungal treatments.

Conclusion

This review highlights the promising potential of using garlic extract in the green synthesis of silver nanoparticles (Ag++), emphasizing its effectiveness and environmental benefits. The eco-friendly approach leverages the bioactive compounds in garlic, which act as natural reducing and stabilizing agents, offering a sustainable alternative to conventional synthesis methods that often involve toxic chemicals and harsh conditions.The biogenically synthesized Ag++ nanoparticles demonstrated significant antifungal activity, making them a potent candidate for combating fungal infections, particularly those resistant to traditional antifungal agents. The use of garlic extract not only aligns with green chemistry principles but also enhances the biocompatibility and safety profile of the nanoparticles, reducing potential adverse effects on human health and the environment.The findings of this review suggest that garlic-extract-mediated synthesis of Ag++ nanoparticles can address the dual challenges of antifungal resistance and environmental sustainability. Future research should focus on optimizing the synthesis process, exploring the underlying mechanisms of antifungal action, and conducting comprehensive in vivo studies to further validate the efficacy and safety of these nanoparticles. By integrating green chemistry practices with advanced nanotechnology, this approach holds promise for developing innovative and sustainable antifungal therapies.

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