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Green Synthesis of Silver Nanoparticles and Their Anticancer Potential: A Review

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Abstract

This review explores the synthesis of silver nanoparticles using green chemistry methods and examines their potential applications in cancer treatment. Green synthesis methods are gaining popularity due to their eco-friendly approach, utilizing natural sources like plant extracts or microorganisms to reduce silver ions into nanoparticles. The review discusses the various synthesis techniques, their advantages, and the mechanisms through which silver nanoparticles exhibit anticancer properties. Furthermore, it analyzes recent research findings on the effectiveness of these nanoparticles against different types of cancer cells, highlighting their promising role in future cancer therapies.

Introduction

Silver nanoparticles (AgNPs) have garnered significant attention in recent years due to their unique physicochemical properties and diverse applications in various fields, including medicine. Of particular interest is their potential role in cancer therapy, owing to their demonstrated cytotoxic effects against cancer cells while sparing normal cells to a certain extent. The conventional methods of synthesizing AgNPs typically involve chemical reduction agents that may pose environmental and health risks. In contrast, green synthesis methods offer a sustainable alternative by utilizing natural sources such as plant extracts, fungi, bacteria, and algae. These methods not only minimize the use of hazardous chemicals but also produce nanoparticles with enhanced biocompatibility and reduced toxicity.

Green synthesis routes employ biomolecules such as flavonoids, terpenoids, polysaccharides, and proteins present in plant extracts to reduce and stabilize AgNPs. The choice of plant extract and conditions of synthesis significantly influence the size, shape, and surface properties of the nanoparticles, thereby affecting their biological activity. The anticancer potential of AgNPs arises from their ability to induce cytotoxicity through multiple mechanisms. These include the generation of reactive oxygen species (ROS), disruption of cellular signaling pathways, and interference with DNA replication and repair mechanisms in cancer cells. Moreover, AgNPs can selectively accumulate in tumor tissues through enhanced permeability and retention (EPR) effect, thereby minimizing systemic toxicity.

Recent research has demonstrated the efficacy of green-synthesized AgNPs against various types of cancer cells, including breast, lung, prostate, and colon cancers. Studies have reported promising outcomes in terms of inhibiting cell proliferation, inducing apoptosis, and enhancing the sensitivity of cancer cells to chemotherapy or radiotherapy when used in combination therapies. This review aims to comprehensively analyze the current state of research on the green synthesis of AgNPs and their potential as anticancer agents. It will explore different green synthesis methods, their advantages over traditional approaches, the physicochemical properties of AgNPs influencing their anticancer activity, and the underlying mechanisms involved in their cytotoxic effects against cancer cells. Additionally, it will highlight key findings from recent studies and discuss challenges and future perspectives for the clinical translation of green-synthesized AgNPs in cancer therapy.

Properties of Nanoparticles

Nanoparticles offer a plethora of intriguing potential uses in a broad range of sectors, such as biomedicine, electronics, nanoparticles, medicines, cosmetics, energy, the environment, catalysis, space technology, and many more. Their physical and chemical properties are also quite remarkable. One of the most important features of nanoparticles is their high surface-to-volume ratio, which is responsible for their exceptional qualities like as hardness, stiffness, high yield strength, flexibility, and ductility. This ratio suggests that surface qualities predominate over bulk properties since there are significant proportions of surface atoms. Additional crucial attributes of nanoparticles encompass a high ratio of surface area to volume, elevated yield strength, pliability, and malleability.

The quantum size effect and the macro-quantum tunneling effect are two further phenomena that are connected to their nanoscale. In fact, the characteristics of bulk materials or tiny particles with the same chemical makeup might differ greatly from those of nanoparticles. Lower melting temperatures, greater specific surface areas, particular mechanical strengths, special optical qualities, and specific magnetizations are a few examples of these variations.

In addition, the size of nanoparticles may affect the physicochemical qualities they possess, and these changes might be subtle or dramatic. When the size of the particles is decreased, for example, the colour of the particles changes, semiconducting materials take on metallic qualities, and nonmagnetic particles transform into magnetic ones. Therefore, from both a scientific and a technical point of view, it is necessary to have a solid grasp of the size-sensitive features that nanoparticles exhibit. It is much more crucial to have the capability to model and anticipate such traits in an effective manner. However, the manner in which nanoparticles are seen and the parameters by which they are characterised are very dependent on the particular application.

Nanoparticles Synthesis Approach

Regarding the creation of nanostructures and the synthesis of nanomaterials, there are generally two different approaches: Both the bottom up and the top down method will be used. The bottom-up strategy involves the downsizing of material components (up to the atomic level), followed by a process of self-assembly that ultimately results in the production of nanostructures. During the process of self-assembly, fundamental building blocks are assembled into more complex and robust structures by use of nanoscale-scaled physical forces. Examples of this include the production of quantum dots during epitaxial growth and the synthesis of nanoparticles from the dispersion of colloidal particles. The top-down method begins with the creation of bigger, macroscopic starting structures, which are then processed in a manner that is subject to external control. Etching via the mask, ball milling, and the application of extreme plastic deformation are three examples of typical procedures.

Need of the Study

The synthesis of silver nanoparticles (AgNPs) through green chemistry methods represents a significant advancement in nanotechnology with potential implications for oncology. Traditional methods of AgNP synthesis often involve harsh chemicals and solvents that can be detrimental to the environment and human health. In contrast, green chemistry principles emphasize sustainable practices by utilizing natural sources such as plant extracts, microorganisms, or biocompatible polymers as reducing agents. This approach not only reduces the environmental footprint but also enhances the biocompatibility of AgNPs, making them suitable for biomedical applications such as cancer therapy. The need for this study arises from several critical factors. Cancer remains a major global health concern, necessitating the development of innovative therapies that can selectively target cancer cells with minimal side effects on healthy tissues. AgNPs have shown promise in this regard due to their ability to induce cytotoxicity in cancer cells through multiple mechanisms, including oxidative stress, DNA damage, and disruption of cellular signaling pathways. Understanding the specific mechanisms underlying their anticancer effects is essential for optimizing their therapeutic

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potential and overcoming challenges such as resistance to conventional treatments. the application of green chemistry principles in AgNP synthesis aligns with global efforts towards sustainable development and environmental stewardship. By exploring green synthesis methods, this study aims to contribute to the growing body of research focused on eco-friendly nanotechnologies that can be scaled up for industrial production without compromising environmental integrity.

Scope of the study

This study focuses on exploring the potential of green chemistry synthesis methods for producing silver nanoparticles (AgNPs) and their application as effective anticancer agents. It encompasses the synthesis of AgNPs using environmentally friendly approaches such as plant extracts and biocompatible polymers, aiming to optimize nanoparticle characteristics like size, shape, and stability. Characterization techniques including UV-Vis spectroscopy, TEM, DLS, and XRD will be employed to analyze nanoparticle properties. The study will evaluate the cytotoxic effects of AgNPs on cancer cells, elucidate underlying mechanisms of action, assess biocompatibility through non-cancerous cell models or animal studies, and investigate potential synergies with conventional cancer treatments. By addressing these aspects comprehensively, this research aims to contribute insights into the feasibility and efficacy of AgNPs as sustainable nanomedicines for future anticancer therapies.

Literature review

Palem, R. R et al (2018) Green synthesis has as one of its primary goals the reduction of the use of hazardous chemicals. Utilizing biological resources such as plants, for instance, is often considered to be risk-free. In addition, plants have reducing and capping agents in their composition. In this essay, We are going to talk about the principles of green chemistry, as well as investigate the production of nanoparticles using plant-mediated processes and novel applications for these nanoparticles themselves.

Ahmed, T., Shahid, M (2020) Cu-NPs has recently gained a lot of significance equivalent to that of gold and silver in a variety of industries; in addition, it has the added advantage of being more cost-effective. It has been suggested that the environmentally benign, relatively inexpensive, and straightforward biosynthesis of copper nanoparticles might serve as a useful alternative to either the physical or the chemical processes now in use. Over the last several years, the synthesis of Cu-NPs from plant extracts has received a substantial amount of attention, and its tremendous contribution to a wide variety of sectors and institutions is worrisome. The medicinal, agricultural, and environmental control applications of phyto-synthesized copper nanoparticles are examined in exhaustive detail here.

Ahn, E. Y., & Park, Y. (2020).The scientific discipline of nanotechnology is one that is currently developing. Nanoparticles are the fundamental building blocks of nanotechnology. The size of a nanoparticle can range from one to one hundred nanometers (nm). An other method of classifying nanoparticles is based on how many dimensions they have, with one-, two-, or three-dimensional nanoparticles being examples. We discuss the physical, chemical, and eco-friendly methods of producing nanoparticles in this paper. Numerous qualitative and quantitative procedures are used to create the nanoparticles that are synthesized. Nanoparticles may be used in a variety of applications, some of which are discussed in this paper.

Mollick, M. M. R., (2019) Nanoscale structures have recently attracted a significant amount of scientific attention, This has caused them to become well-known as an effective intermediary between atomic and molecular structures and bulk size. Consequently, experts from a wide range of industries have turned their attention toward the creation of novel methods in recent years, protocols, and designs for the creation of nanostructures that are dependable, sustainable, environmentally friendly, nontoxic, and biodegradable. Green chemistry-based nanostructure synthesis is also likely to stick to a solvent system of choice, which affects financial and environmental factors including safety and health effects. This is necessary in order to make the process sustainable. Therefore, in light of the twelve tenets that have been established as preconditions for the practise of green chemistry, With the intention of providing an overview of the several types of solvents that, in essence, may be categorized as green solvents, the objective of this chapter is to give an overview.

C. Shanmugam, G. Sivasubramanian, B. (2015) Studies on green synthesized silver nanoparticles (AgNPs) using Abelmoschus esculentus (L.) pulp extract have shown promising results in both anticancer and antimicrobial applications. The green synthesis method utilizes the reducing and stabilizing properties of the pulp extract to produce AgNPs with controlled size and morphology. In terms of anticancer applications, these AgNPs have demonstrated cytotoxic effects against various cancer cell lines in vitro. They induce apoptosis, inhibit proliferation, and disrupt cellular processes crucial for cancer cell survival, highlighting their potential as effective anticancer agents. Additionally, the antimicrobial properties of AgNPs synthesized using Abelmoschus esculentus pulp extract have been investigated. They exhibit significant antimicrobial activity against a wide range of pathogens, including bacteria and fungi, suggesting their potential in combating microbial infections. The mechanism of action involves the interaction of AgNPs with microbial cell membranes, leading to membrane damage, oxidative stress, and ultimately cell death. These findings underscore the dual therapeutic potential of AgNPs synthesized through green methods using Abelmoschus esculentus pulp extract, emphasizing their role in advancing sustainable nanotechnologies for biomedical and environmental applications. Future research aims to further elucidate the underlying mechanisms and optimize synthesis conditions to enhance the efficacy and safety of these nanomaterials for broader clinical and industrial use.

S. Arokiyaraj, S. et al (2017) Shell nanoparticles anchored on graphene oxide represent a novel recyclable nanocatalyst for the reduction of nitrophenol compounds. This advanced catalyst combines the high surface area and excellent electronic properties of graphene oxide with the catalytic activity and stability provided by shell nanoparticles. The synthesis involves anchoring shell nanoparticles, typically composed of metals such as palladium, platinum, or gold, onto the surface of graphene oxide through chemical or physical methods. This hybrid structure enhances catalytic performance by facilitating electron transfer processes and providing active sites for nitrophenol reduction reactions. In applications, this nanocatalyst demonstrates efficient reduction kinetics and high selectivity towards converting nitrophenol compounds to their corresponding amino derivatives under mild conditions. The catalytic process involves the adsorption of nitrophenol molecules onto the catalyst surface followed by electron transfer and hydrogenation reactions facilitated by the shell nanoparticles. Importantly, the graphene oxide support allows for easy separation and recovery of the catalyst from reaction mixtures using simple filtration or magnetic techniques, enabling its reuse in multiple catalytic cycles without significant loss of activity. the integration of shell nanoparticles anchored on graphene oxide as a recyclable nanocatalyst for nitrophenol reduction presents a sustainable and effective approach to environmental remediation and chemical synthesis processes. Further research aims to optimize catalyst composition, structure, and synthesis methods to enhance catalytic efficiency, stability, and applicability across diverse industrial and environmental settings.

V.K. Gupta, N. Atar, M.L (2014) The synthesis and characterization of Cu, Ag, and Au dendrimer-encapsulated nanoparticles (DENs) have been explored for their application in the reduction of 4-nitrophenol to 4-aminophenol. These DENs are synthesized by encapsulating metal nanoparticles (Cu, Ag, Au) within dendrimer molecules, which serve as stabilizers and provide a controlled environment for the nanoparticles. Characterization techniques such as UV-Vis spectroscopy, transmission electron microscopy (TEM), and dynamic light scattering

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(DLS) confirm the formation of well-defined dendrimer-encapsulated structures with uniform particle size and dispersion. In catalytic applications, these DENs exhibit efficient reduction kinetics due to the high surface area and catalytic activity of the metal nanoparticles, enhanced by the dendrimer's stabilizing effect. The reduction of 4-nitrophenol to 4-aminophenol occurs through catalytic hydrogenation facilitated by the metal nanoparticles, where the dendrimer shell aids in substrate adsorption and reaction kinetics. Furthermore, the dendrimer encapsulation ensures robust catalyst stability and recyclability, allowing for multiple reaction cycles without significant loss of activity. Cu, Ag, and Au dendrimer-encapsulated nanoparticles show promise as effective catalysts for the reduction of nitrophenol compounds, highlighting their potential in green chemistry applications for environmental remediation and chemical synthesis processes. Ongoing research aims to optimize synthesis methods and explore additional catalytic functionalities of these versatile nanomaterials.

V.N. Ariharan et al (2012) The green chemistry revolution has opened up a world of possibilities, including alternative feedstocks, more eco-friendly reaction conditions, reduced energy use, and the creation of molecules with lower toxicity and inherent safety. The origins and basis of green chemistry in order to achieve the ecological and financial advantages of a sustainable future. One important aspect of sustainable chemistry is the optimization of chemical processes and products with respect to criteria such as material and energy consumption, inherent safety, toxicity, environmental degradability, and so on. Although there has been great strides in environmental chemistry, green chemistry, and the evaluation of chemical products for their impact on the environment, not all areas of chemical research have fully acknowledged the social aspect of sustainable chemistry. This highlights the critical need to integrate sustainable chemistry into chemical education from the start.

S.K. Mohanty et al (2014) The principles of green chemistry may be integrated into many aspects of the textile industry, from raw material extraction through finished product packaging. This article makes an effort to examine the many contexts in which green chemistry has been used in the textile industry, to assess the potential for further deployment of its principles, and to assess the relevance and urgency of making the transition to more sustainable methods. The overview begins with a discussion of the importance of green chemistry and its application to the dyeing of textiles and the processing of a few major textile finishes. Fabric dyeing, as well as antibacterial, flame retardant, water repellent, and crease-resistant finishes (in comparison to traditional finishing chemicals) are just a few examples of where green chemistry has been put to use in the textile industry. We address the current chemicals and the toxicological risks they pose, highlighting the critical need for sustainable chemistry. The most up-to-date practices for creating environmentally friendly chemicals to use in the various coatings will also be covered. Green chemistry's potential uses are discussed, along with the challenges and opportunities that lie ahead, in the review's last section.

S. Joseph, B. Mathew et al (2015) Since green chemistry is an initiative to reduce risks associated with chemical preparation, reaction, and the use of the resulting product, it stands to reason that this concept will gain prominence in the chemistry classroom. Examining how college students feel about green chemistry and its practical applications is the primary goal of this research. 190 people were asked to fill out questionnaires. Students' perspectives on green chemistry and its practical applications were acquired through questionnaires. Most students surveyed expressed support for implementing green chemistry concepts, although it was found that some respondents still believed it was difficult or did not wish to do so in certain contexts. If professors are serious about integrating green chemistry concepts into their curricula, they may need to give certain details greater weight.

Research Problem

The research problem addressed in this study is centered around the green chemistry synthesis of silver nanoparticles (AgNPs) and their potential as effective anticancer agents. Traditional methods of nanoparticle synthesis often involve hazardous chemicals and solvents, which pose environmental risks and health concerns. In contrast, green chemistry principles emphasize sustainable practices by utilizing natural sources such as plant extracts or biocompatible polymers as reducing agents to produce AgNPs.

The specific challenge lies in optimizing green synthesis techniques to reliably and efficiently produce AgNPs with tailored properties suitable for biomedical applications, particularly in cancer therapy. This includes controlling nanoparticle size, morphology, and surface chemistry to enhance their stability, biocompatibility, and therapeutic efficacy. Furthermore, understanding the mechanisms by which AgNPs interact with cancer cells and induce cytotoxic effects is crucial for maximizing their anticancer potential while minimizing off-target effects on healthy tissues. It requires the development and characterization of AgNPs using state-of-the-art analytical techniques to ensure their structural integrity and biological activity. Additionally, comprehensive in vitro and in vivo studies are necessary to evaluate the safety profile, pharmacokinetics, and long-term effects of AgNPs, paving the way for their translation from laboratory research to clinical applications. this research problem aims to advance the field of nanomedicine by providing sustainable and effective strategies for developing AgNPs as innovative tools in the fight against cancer, while also contributing to the broader goal of green chemistry in promoting environmentally friendly technologies.

Conclusion

The review underscores the growing significance of green synthesis methods for producing silver nanoparticles (AgNPs) and their promising potential as anticancer agents. Green synthesis offers a sustainable approach that minimizes environmental impact and enhances biocompatibility compared to conventional chemical methods. Throughout this review, we have highlighted the diverse biological activities of AgNPs synthesized using green techniques, particularly their ability to induce cytotoxic effects in cancer cells through mechanisms such as ROS generation, apoptosis induction, and interference with cellular signaling pathways. These nanoparticles have shown specificity towards cancer cells while sparing normal tissues to a certain extent, which is crucial for reducing systemic toxicity in cancer therapy. The choice of green synthesis route influences the physicochemical properties of AgNPs, including size, shape, and surface characteristics, which in turn impact their biological efficacy. The use of natural extracts rich in biomolecules as reducing and stabilizing agents adds another layer of complexity to optimizing nanoparticle synthesis for therapeutic applications. advancements, several challenges remain, including standardizing synthesis protocols, ensuring reproducibility of nanoparticle properties, and navigating regulatory requirements for clinical translation. Further research is needed to fully elucidate the mechanisms underlying the anticancer activity of green-synthesized AgNPs and to explore their potential synergistic effects in combination therapies with existing treatments. the integration of green-synthesized AgNPs into clinical practice holds promise for enhancing cancer treatment outcomes through targeted, effective, and minimally toxic therapies. Continued interdisciplinary collaboration between chemists, biologists, and clinicians will be essential to harnessing the full potential of AgNPs in the fight against cancer.

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