"Nature-Inspired Nanotech: Integrating Ayurvedic Knowledge In Green Nanoparticle Synthesis For Modern Challenges"

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Abstract:
In recent years, green synthesis of nanoparticles using plant-based materials has emerged as a sustainable and eco-friendly approach within nanotechnology. Rooted in India's traditional medicinal systems like Ayurveda, this method offers a cost-effective and environmentally benign alternative to conventional chemical synthesis. Concurrently, water contamination persists as a major global concern, driving the need for innovative purification technologies. Nanotechnology presents transformative solutions for water treatment through the use of nanomaterials such as nanoparticles, nanocatalysts, nanomembranes, and nanosensors, which demonstrate remarkable adsorption, catalytic, and filtration capabilities due to their high surface-area-to-volume ratio and unique physicochemical properties. Among these, biosynthesized silver, gold, and platinum nanoparticles have shown significant potential across diverse sectors, including environmental remediation, biomedicine, and targeted drug delivery. This review highlights the integration of traditional herbal knowledge with modern nanobiotechnology, showcasing a promising path toward sustainable material development and advanced healthcare solutions.

Keywords: Nanotechnology, Water Purification, Eco-friendly, Arsenic Removal, Nanobiotechnology

Introduction

The study of science can't get away from this development and stay significant and critical to mankind. Science applies a colossal impact on human activity and is subsequently inseparably interwoven with the powers that guide human activity particularly morals and certain types of energy. Nowadays, nanoparticles are synthesized using various techniques, among which chemical methods, lithography, and laser ablation are quite expensive, time-consuming, and environmentally harmful. Green chemistry to be a component of societal practice, we'd like to make a knowledgeable green chemistry community comprised of pros, teachers, students, and therefore the public. Different plants have shown potential for agglutination of nanoparticles, prompting scientists and technologists to explore the use of plants and their products in nanoparticle synthesis. The presence of enzymes, phytochemicals, proteins, and other components in plants is commonly utilized in synthesizing silver nanoparticles using plant extracts (Kulkarni et al., 2011). Nanoparticles exhibit a high surface area to volume ratio, which significantly enhances their chemical reactivity, catalytic activity, and other functional properties. As particle size decreases, a larger proportion of atoms are present on the surface rather than in the bulk, making them highly effective in applications ranging from medicine to electronics. For example, cadmium sulfide (CdS) and zinc sulfide (ZnS) nanoparticles are widely used in optoelectronic devices such as solar cells and light-emitting diodes due to their superior luminescence properties. Gold nanoparticles (AuNPs) play a crucial role in biomedical applications, particularly in targeted drug delivery and imaging, due to their biocompatibility and ease of functionalization. Zinc oxide (ZnO) nanoparticles exhibit strong antibacterial and UV-blocking properties, making them valuable in sunscreen formulations and antimicrobial coatings. Similarly, silver nanoparticles (AgNPs) have potent antimicrobial activity and are extensively used in wound dressings, textiles, and water purification systems. According to Malarkodi et al. (2014), these nanoparticles have revolutionized multiple fields, including medicine, energy, and environmental science. Their ability to interact efficiently at the molecular level due to their high surface area makes them indispensable in modern technology, offering enhanced performance in various industrial and scientific applications.

The term "nanotechnology" was first introduced by Taniguchi in 1974, who defined it as a technology involving the processes of separation, consolidation, and deformation of materials at the level of individual atoms or molecules (Iqbal et al., 2012). "Nanotechnology is the application of science to control matter at the molecular level". Tremendous growth in nanotechnology has opened up novel fundamental and applied frontiers in materials science and engineering, such as nano biotechnology, quantum dots, surface-enhanced Raman scattering (SERS) and applied microbiology. Nanotechnology also focuses on the study of nanomaterials, which exhibit remarkable properties, functionalities, and phenomena due to their nanoscale dimensions (Khan et al., 2017). Developments in the organization of nanoscale structures into predefined superstructures ensure that nanotechnology will play a critical role in many key technologies. It is gaining importance in areas such as mechanics, optics, biomedical sciences, chemical industry, electronics, space industries, drug-gene delivery, energy science, catalysis, optoelectronic devices, photoelectrochemical applications, and nonlinear optical devices. For instance, nanometre-scale geranium quantum dots (less than 10 nm) could be controllably formed for novel optoelectronic device applications such as single electron transistors (SETs) and light emitters. The ability to tune the optical absorption/emission properties of quantum dots (semiconductor nanoparticles) by simple variation in nanoparticle size is particularly attractive in the facile band-gap engineering of materials and the growth of quantum dot lasers.

Water is an essential natural resource and a fundamental necessity for human survival. Although over 70% of the Earth's surface is enveloped by the hydrosphere, only about 2.5% of this is accessible as freshwater, which exists in rivers, glaciers, groundwater, and atmospheric vapor. Ensuring the availability of clean and affordable drinking water has emerged as a critical challenge in the 21st century, necessitating effective planning and sustainable management practices. In recent decades, rapid population growth and excessive extraction of groundwater have significantly contributed to water scarcity in various regions around the globe. Consequently, the volume of wastewater has increased substantially. In the absence of appropriate wastewater treatment facilities, especially in developing nations, pollution levels in the already scarce freshwater reserves have worsened. Recognizing this growing crisis, governments worldwide have introduced stringent water quality standards and advanced treatment protocols. These regulatory actions have spurred scientific interest and innovation in water purification methods, both in developed and developing nations. Various conventional techniques—such as anion exchange, liquid distillation, adsorption using activated carbon, ultrafiltration, reverse osmosis, ultraviolet (UV) filtration, and deionization—have been employed to purify contaminated water. However, these methods often face limitations related to complexity, high operational costs, and inefficient energy usage, which hinder their widespread application.

In light of these challenges, nanotechnology has emerged as a promising alternative. It offers innovative, energy-efficient solutions that not only ensure toxin-free environments but also promote sustainable resource conservation.

Applications of Metal Nanoparticles in Medicine and Pharmacy

Metal nanoparticles, particularly gold and silver, play a pivotal role in various medical and pharmaceutical applications. These nanoparticles are extensively utilized in the interdisciplinary domain of nanobiotechnology, owing to their unique physicochemical properties.

Gold nanoparticles (AuNPs) are among the most widely used for biomedical purposes. One significant application involves oligonucleotide-capped gold nanoparticles, which are employed in the detection of polynucleotides and proteins. A range of analytical and characterization techniques have been utilized for this purpose, including atomic force microscopy (AFM), gel electrophoresis, scanometric assays, surface plasmon resonance (SPR) imaging, amplified voltametric detection, chronocoulometry, and Raman spectroscopy.

Additionally, gold nanoparticles have been applied in various diagnostic and therapeutic platforms, such as immunoassays, protein assays, cancer diagnostics (notably in the detection of cancerous cells), and capillary electrophoresis. In clinical medicine, they are used as biological markers in screening tests. Following cellular internalization, gold nanoparticles can function as localized thermal scalpels, delivering targeted hyperthermia to ablate cancer cells. Moreover, they have demonstrated the ability to induce apoptosis in B cell chronic lymphocytic leukemia (CLL), highlighting their potential in oncological therapies.

Silver nanoparticles (AgNPs) have also attracted considerable interest due to their broad-spectrum applications. These include roles in integrated electronic circuits, biosensors, bio-labeling, filtration systems, antimicrobial fibers, cell electrodes, and general antimicrobial agents. Their strong antimicrobial activity has led to widespread use in medicine, industry, animal husbandry, food packaging, personal care products, health applications, and military equipment.

AgNPs exhibit potent antimicrobial effects against a wide range of pathogenic microorganisms, including *Escherichia coli*, *Bacillus subtilis, Vibrio cholerae*, *Pseudomonas aeruginosa*, *Treponema pallidum* (causative agent of syphilis), and *Staphylococcus aureus*. Their effectiveness in controlling microbial infections makes them invaluable in both clinical and non-clinical settings.

Conclusion

The growing urgency for advanced and sustainable water treatment technologies is driven by the critical need to eliminate micropollutants and improve industrial treatment processes to ensure access to safe drinking water. Arsenic contamination in groundwater—originating from both natural and human activities—poses a major public health risk globally, particularly in rural and developing regions where millions rely on untreated groundwater for daily use. With per capita freshwater availability steadily decreasing, innovative solutions are essential. Nanotechnology has emerged as a leading candidate, offering high-efficiency treatment methods and enabling the safe use of alternative water sources. Its modular design and operational flexibility reduce the dependency on large-scale infrastructure, opening new possibilities for water purification and the economical use of non-traditional water supplies. Nanomaterials, owing to their high surface area, rapid reactivity, low cost, and eco-friendly nature, are increasingly seen as viable alternatives to conventional treatment methods. Nonetheless, concerns about nanoparticle accumulation in the environment and the challenges of scaling and integrating nanotechnology into existing water systems remain significant. Even so, its potential—especially for decentralized applications, portable purification units, and remediation of heavily polluted water—positions nanotechnology as a promising frontier in future water treatment strategies.

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