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"A Review of Silver Nanoparticles: Synthesis techniques and their influence on the textile for antibacterial property"

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Abstract:
Much attention has recently been directed to developing bactericidal qualities for surfaces close to people because of the increased awareness of personal cleanliness and health. Regarding closeness, the daily fabrics come into contact with the human skin more often than any other surface. Because of their soft and porous surface, fabrics can serve as excellent breeding grounds for bacteria, allowing them to adhere, multiply, and form biofilms. Thus, it is clear that bacterial stains contaminate the fabrics and there is a rapid spread of diseases. Bacterial growth is predominant in fabrics, especially in sectors like health care, military uniforms, lingerie, etc. Accordingly, several nanoparticles are developed and incorporated into the fabric to enhance the antibacterial multipurpose action. One of the metals, such as silver nanoparticles, gives enormous advantages to textiles. Therefore, this review aims to discuss silver nanoparticles' multifunctionality and utilization for developing antibacterial fabrics.

Keywords: Silver nanoparticles, Antibacterial, Textile, Health and hygiene.

1. Introduction

One of the main issues the world has been facing for several years is environmental changes through degradation, which has impacted the global economy and society. In response to this issue, textiles and their products are often considered environmentally benign and renewable resources, significantly increasing the use of natural fibers (Okur & Yaradanakul, 2022). Due to concerns about health and lifestyle, eco-friendly fibers are in greater demand for woven and patterned textiles (Rani et al., 2019). Due to the rise in need for woven and patterned textiles, eco-friendly fibers, such as cotton and linen, are the two newer fibers increasingly popular for various applications (Okur & Yaradanakul, 2022). Many textile finishers are now interested in the high level of bacterial resistance that may be achieved with minimal processing costs and straightforward application processes (Lee et al., 2003)

Nanoparticles are of tremendous interest because of their tiny size (in nm) and high surface-to-volume ratio, which alters their chemical and physical properties compared to most of the same chemical composition (Jadoun et al., 2021) (Antinate Shilpa et al., 2022). In recent decades, it has been used to develop antimicrobial textiles. It is found that more than 650 different kinds of bacteria, viruses, and fungi can be killed or their growth inhibited by silver and its compounds, thereby maintaining the microelement, which is a necessary component of all living things (KHE et al., 2019). Nano finishes (zinc oxide, titanium oxide, silver oxide nanoparticles, and silver nanocolloids) impact natural (cotton, wool, and silk) and some synthetic fibers on antimicrobial properties. When compared with other metals, silver nanoparticles are among the most researched nanomaterials for use in biomedicine; their antiviral, antibacterial, and anticancer properties have been emphasized with their application. Additionally, because of their nontoxicity and biocompatibility, they provide better hydrophobicity, oleophobicity, etc (Granados et al., 2021).

The study aims to systematically review nano-finish synthesizing techniques and the role of silver nanoparticles in textile applications for their antibacterial activity.

2. Literature review

2.1. Synthesis of nanoparticles and preparation methods

Synthesis of silver nanoparticles occurs in a liquid, gas, or vapour phase; smaller nanoparticles are produced in the gas and vapour phases. Although the liquid phase will provide the nanoparticles with softer circumstances, the size will be determined by the solution's phase separation or chemical reaction (Almatroudi, 2020). The advantages and disadvantages of each method are valuable. In contrast to inorganic nanoparticles, which can be produced under more severe circumstances, organic nanoparticles are created at moderate temperatures, pressures, and pH levels if necessary. There are two approaches to preparing nanoparticles: (1) top-down and (2) bottom-up. Process that manipulates larger particles to smaller nanoparticles are called the top-down approach. The bottom-up approach brings the atoms and molecules together to a medium state. The methods for applying nanoparticles can be selected based on the product. (Oake et al., 2019a). According to (Tran et al., 2013)Silver nanoparticles have superior antibacterial and antifungal properties. It is used on materials in the packaging and medical industries to guard against contamination and microbial growth. Risk potential criteria for the environment and human health need more investigation. When precautions are followed regarding use and disposal to reduce dangers, advanced applications involving AgNPs show promise. (Vu et al., 2018), using sodium borohydride (NaBH4) and starch as a stabilising agent, synthesized silver nitrate (AgNO3) and discovered spherical-shaped nanoparticles measuring 8 ± 4 nm that demonstrated potent antibacterial activity against Gram-positive Staphylococcus aureus (*S. aureus*) and Gram-negative *Escherichia coli* (E. coli).

2.2 Types of nanoparticle synthesis

Three techniques synthesise nanoparticles. (1) Physical, (2) Chemical, and (3) Biological. From these methods, chemical and physical methods are very rarely used due to their toxic substances and yield aspects. Physical methods are traditional methods produced by consuming heat energy, radiation with high energy, and mechanical force for compression or contraction of material, evaporating, and melting. Majorly, it is conducted using a top-down technique, which is free of solvent, homogeneously monodispersing etc, and is used for developing nanoparticles (Kumari et al., 2023; Natsuki, 2015). Chemical synthesis is widely used for its easy synthesis of nanoparticles in solution form, mainly involving three ingredients: metal precursor, reducing agent, and stabilising/capping agent. (Sakilam & Reddy, 2023)

Biological techniques are increasing rapidly due to their simplicity and being environmentally safe. Green synthesis provides advantages over conventional techniques but has drawbacks, such as prolonged synthesis periods, higher production costs, purification difficulty, and the release of dangerous, harmful derivatives. Most importantly, bacteria, fungi, yeasts, algae, etc were used as reducing and/or stabilising substances. (Tran et al., 2013) These techniques have several important advantages over earlier ones, such as a quick reaction time, the production of relatively uniform particles with a small diameter, a quick reaction at room temperature, and the use of chemical reagents that are water-soluble, inexpensive, manageable, and free of byproducts.

2.3. Influence of nanoparticle size on nano finishing

These particles range in size from one nanometre to one thousand nanometres, making them somewhere between the size of a virus and an antibody. Nanoparticles are of three different types: (1) zero, (2) one, and (3) two-dimensional. Depending on these types of shapes, the nanoparticles vary from spherical, triangular, long hollow structures, thin filaments, polygonal shapes to cubes. When compared to larger nanoparticles, smaller ones typically produce significantly lower wavelengths (Dolez, 2015; Oake et al., 2019b). Compared to all other shapes of particles, the triangular shape gives a higher positive charge to the nanoparticle

NPs' sizes can be changed based on their intended purpose. The environment and people are impacted by the use of nanoparticles smaller than 50 nm (Gokarneshan et al., 2012). (Sakilam & Reddy, 2023) Reported that the size is modified according to the sector it applies to. In 2023, (Syduzzaman et al., 2023) Investigated the cruciality of the shapes of nanomaterials and their impact in a wide range to produce better surfaces with antimicrobial, UV-blocking, anti-static, superhydrophobic, and self-cleaning qualities. It also has enormous needs for consumer goods, safer health, and innovative fabrics. Sustainable development can be defined as the development that balances the needs of the present with the capability of future generations to meet their individual needs (Jadoun et al., 2021).

2.4 Overall importance of nanoparticles on textiles

Modern applications of nano-enabled technologies enhance the durability of fabrics and develop an increased affinity for them and prolonged longevity. The coating of nano will retain its air permeability and quality throughout. Among all these, a few other techniques used to impart nano on fabrics include: (1) Padding, (2) Spraying, (3) Transferring by printing, (4) washing, (5) Rinsing. It offers excellent attributes like water repellence, antibacterial property, wrinkle resistance, improved dyeability, etc. Durability is greater for fabric with nanoparticles when compared to other finishes. (Panchal & Patel, 2025). Gold, silver, and copper, are applied in the textiles for antibacterial and antiodor properties, TiO_2, ZnO_2 are for UV absorption and electric conductivity (Dolez, 2015). Applications related to nano silver have taken a greater step towards commercialization. Almost 313 items include nano silver, growing faster in each consumer product (Edwards-Jones, 2009). Tran et al reported that short reaction time and a smaller diameter produce uniform particles when the reaction time is at room temperature. They found that most solvents are chemical-based, water-soluble, and not organic. Those are cheap and easy to handle. Hence, these methods are safe and friendly. According to Antinate Shilpa et al. (2022), nanoparticles mitigate bacterial growth by utilizing the metal/metal oxides over the required fabrics. All other physical properties are biocompatible when nanoparticles are applied to fabrics in a limited way. The results showed better durability after 50 wash cycles.

2.5 Function of silver nanoparticles in textile applications for antibacterial activity

Antibacterial capabilities against various gram-positive and gram-negative bacteria have been demonstrated experimentally by silver ions in silver nitrate aqueous solution. The emergence of nanotechnology made it feasible to create silver nanoparticles with distinct chemical, physical, and biological characteristics. Several investigations have verified that silver nanoparticles are antibacterial against various microorganisms (Anees Ahmad et al., 2020a; Jalab et al., 2020). According to Shaikh et al. (2023), silver is used for leaching in medical apparel. The 0.5% concentration of silver solution will cause the skin to be allergic. A vast application of silver nitrate is found in biology, chemical synthesis, and medicine. Henceforth, it is concluded that silver macromolecules are hereby replaced with AgNPs to reduce their extent of harm. Alongside Openshaw et al. (2016), reports that various new fibers and techniques could be cheaper, easier, and biodegradable to produce products. Henceforth, due to this revolution, silver nanoparticles have become an excellent choice for most researchers and daily consumers as an agent for antibacterial properties. (Anees Ahmad et al., 2020a)explored and reported that silver nanoparticles have excellent antimicrobial properties against bacterial infections. Many researchers have studied the antibacterial properties of the application of silver nanoparticles, and it has been proven to enhance the fabric. (Granados et al., 2021)comprehensively discusses changes in cotton fabric by coating metal nanoparticles with the pad dry cure method for obtaining antibacterial and anti-

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inflammatory characteristics. As a result, Gram-negative *E.coli* and Gram-positive *S.aureus* were reported positive.

Table 1: Silver nanoparticles and their antimicrobial property

Author(s) & year	Type of research	Sample/material	Key findings	Limitations/Gaps	Relevance
(KHE et al., 2019)	Experimental	Silver nanoparticles	Effective antibacterial activity	Evaluation of toxicity and pathogen screening	AgNPs result in positive antimicrobial agents
(Vigneshwaran & Arputharaj, 2020)	Literature review	Cotton	100% bacterial reduction,	A drop may occur in antimicrobial effects after 10-20 wash cycles	Benefits for medical and healthcare textiles
(Anees Ahmad et al., 2020b)	Experimental	Cotton, in-situ deposition of AgNPs	Enhanced antibacterial activity	Long-term nanoparticle release's effects on stability, safety, and the environment were not consistently evaluated.	Multifunctional applications (medical, protective, or self-cleaning fabrics)
(Saleem & Zaidi, 2020)	Comprehensive literature review	Diverse materials on nanotextiles	Increased utilisation of nanotechnology across the textile industry, providing extensive advanced functional properties.	Life cycle and environmental data are insufficient	Sustainable needs for various applications for industries and academic stakeholders.
(Andra et al., 2021)	Survey	Textile fibers (Natural and synthetic) treated with nanoparticles like Ag, ZnO, and TiO_2.	Nanomaterials provide strong antimicrobial properties, durable and multifunctional.	Cytotoxicity is discussed in limited.	Safety assessments, eco-certifications, and their regulatory permissions for wearable products
(Granados et al., 2021)	Literature review	Cotton- Pad dry cure	Ag exhibits effective bacterial strains, provides anti-inflammatory and antibiotic agents.	Coating reduces the tensile strength or air permeability	Applicability for medical and sportswear textiles
(Ramani et al., 2023)	Experimental in vitro comparative study	Silk- AgNPs Coated, AgNPs aloe vera	Increased antibacterial efficiency in AgNP is only compared to plain.	Durability and biocompatibility are limited	Safer for biomaterial research applications

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(Dube & Okuthe, 2025)	Experimental- In situ fabrication	Cellulose nanofibers	Improved antibacterial efficacy by also significantly reducing cytotoxicity.	Reduced cytotoxicity, long-term durability, and silver ion release	Applications of medical textiles for long-term stability
(Dos Santos et al., 2025)	Experimental quantitative	Cotton and polyamide, commercial viz synthesized AgNPs	Plasma treatment reduces the uptake	The leaching of silver is not clear	Safe antimicrobial textiles, evaluation of exposure, and regulatory risk
Shabnam Sharmin et al., 2021	Scientific exploration	Cotton, polyester, and non-woven coated with Ag, Cu, or ZnO NPs.	Durability of NPs can be retained after multiple washes, and they adhere to the material.	Environmental toxicity has not been thoroughly researched with regard to NP size, chemistry, and its effects on the ecosystem.	Great value in healthcare, sports, military, and consumer products

such as textile science, medicine, agriculture, sensors and detectors, and catalysis (Ke Thanh & Phuong Phong, 2009). According to the literature review, it is clear that silver nanoparticles are emphasized for their antibacterial property for better protection against bacteria.

3. Conclusion:

This review presents various AgNPs preparation techniques and their characteristics. Additionally, the nanoparticle's size and other variables influencing the characteristics of the fabric were clarified. The fundamental benefit of these technologies is that they are inexpensive, easy to handle, free of dangerous byproducts, environmentally friendly, and have a stronger response when the particle size is reasonably consistent, well-maintained temperatures, and with the soluble chemical reagents in water. This promotes its use in a wide range of environmental and biomedical applications and other expanding consumer product needs. However, before the various nanomaterials are commercially accepted, their effects on human health and the environment must be thoroughly investigated and proven.

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