



Localized Surface Plasmon Resonance Property of Ag-Nanoparticles and Prospects as Imminent Multi-Functional Colorant

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Abstract : Due to the Localized Surface Plasmon Resonance (LSPR) property of silver nanoparticles (Ag-Nps) it exhibits adaptable colors depending on the synthesizing measures. LSPR properties has strong absorption and scattering properties along with strong interaction towards light at definite wavelengths for the conductive electrons into the metal surface. The LSPR property of silver nanoparticles gives rise to captivating colors. Besides silver nanoparticles has strong cytotoxicity towards a broad range of microorganisms, low toxicity to human cells, high selectivity, long term durability, increased dye ability and biocompatibility are drawing a tremendous level of attention from both academic research and industry. Silver nanomaterial's, due to their unique properties are particularly attractive for production of textiles surfaces with novel properties such UV protection, water resistant, self-cleaning and antimicrobial activity. Recent advances about the use of silver nanomaterial's as novel colorants and antimicrobial agents for different textiles materials has been focused in this study to designate possible challenges and further scope of research in this field.

Keywords: Colorants; Silver nanoparticles; Localized Surface Plasmon Resonance (LSPR); Natural and Manmade fibers

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1. Introduction

Dyeing of cotton fabrics with anionic dyes such as direct and reactive dyes requires the presence of large quantities of electrolyte to increase dye uptake, resulting in serious environmental problems. As a result of this process, large volumes of wastewater, containing significant amounts of dyes and chemicals are discharged from a typical cotton dye house [1, 2]. Pollution due to the discharge of industrial effluents including textile, electroplating, chemical and other industry wastewaters is of major concern recently because of their toxicities and threat to the human life and environment [3-8]. In particular, textile effluents have gained increased attention because the extensive release of synthetic dyes has caused considerable environmental pollution (e.g., they produce unsightly color even at very low concentration, affect the photosynthetic activity of aquatic plants and raise the chemical oxygen demand). Importantly, the accumulation of dyes in water can seriously damage food chains of human and animals [9, 10]. The textile industries have been researching for new and alternative technologies to meet both the quality and eco-friendly production [11-15]. In this stage, Best method would be to use modern nano dyes for coloration of fabrics. Researchers around the world found growing interest on this particular field.

Ag nanoparticles has exclusive and convenient properties, including surface enhanced spectroscopy [16, 17], biosensors [18, 19], and plasmatic devices [20, 21]. Most of these applications are based on the LSPR of silver nanoparticles. LSPR properties has strong absorption and scattering properties along with strong interaction towards light at definite wavelengths for the conductive electrons into the metal surface [22-24]. The LSPR property of silver nanoparticles gives rise to captivating colors. This optical feature of silver nanoparticles is related to particle shape, [25] size, [26] composition, [27] environment, [28, 29] and interspaces. Among them, the shape and size of nanoparticles govern the LSPR optical features, The LSPR of silver nanoparticles can be further adjusted by controlling the shape and size of nanoparticles. [30]. Silver nanoparticles have scattering and absorption extinctions spectrum cross sections more than ten times larger than their physical cross sections. [31]. In prehistoric periods silver nanoparticles were applied for the coloration of ceramics and glasses. [32, 33]. According to "Dichroic" effect of *Lycurgus cup* [34], it had also application for brighter color in renaissance pottery. Recently researches are going on for further development of coloration of textiles through the synthesis of silver nanoparticles. [35]. Merino wool fibers were colored through the implementation of LSPR properties of silver nanoparticles by Kelly and Johnston [24]. Silver nanoparticles remained synthesized by means of the trisodium citrate as reducing agent for the coloration of wool fibers and they have also decided that by using trisodium citrate it is easy for the binding of silver nanoparticles with the amino acids of keratin of protein fiber in the merino wool fabric. Falletta *et al.* prepared the silver nanoparticles over sodium borohydride or by irradiation with UV light along with the polyacrylates. However, Cotton as one of many other natural fibers have versatile applications as garments of different items because of its usual smoothness, high hygroscopicity and heat absorbent properties [36]. Coloration of fibers is pivotal for application of cotton in the textile industry. Light fading of dyes is a common phenomenon in textile research. [37, 38] The silver nanoparticles are different from traditional dyes, in that it is not the chromophore of traditional dyes but the shape and size of nanoparticles that determine the colors. In addition to color, the silver nanoparticles have significant antibacterial activity, which has been reported in the literature. However, most of these antimicrobial agents suffer from many disadvantages such as action on non-target microorganisms, toxicity to the environment and low durability of antimicrobial finish. [39] To overcome these problems intense research efforts are being made to investigate the possible effects of

nano science and nanotechnology in textile industry. Researchers have devoted special attention to various preparation techniques including gamma irradiation, photo-catalytic reduction, chemical reduction, microwave processing, photo-chemical method, metallic wire explosion, sonochemical, polyols, electron irradiation, and biological methods for the synthesis of silver nanoparticles [40]. The most accepted mechanism is on the basis of their interaction with cell membrane causing extensive cell surface alternations and permeability, leading to intracellular leakage of cytoplasm and finally death of microorganism. Interaction with thiol group compounds found in the respiratory or vital enzymes of bacterial cells is another route described to explain their action-mechanism. Silver binds to the bacterial cell wall and cell membrane and inhibits the respiration process causes micro-organism structural changes, and then inhibits the metabolic pathway through producing reactive oxygen species.[41] Other mechanism suggests the antimicrobial activity due to interaction of silver nanoparticles with the sulphur and phosphorus of the DNA, leading to or inducing problem in its replication ability and eventual cell death.[42] The antimicrobial mechanism of silver nanoparticles is shown in Figure 1. A more detailed discussion about the mechanism of action of silver nanoparticles is described in a recent review article by Duran *et al.*[43]

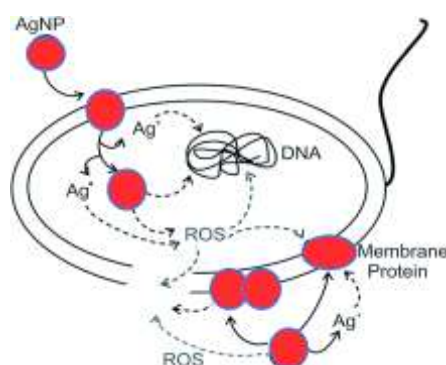


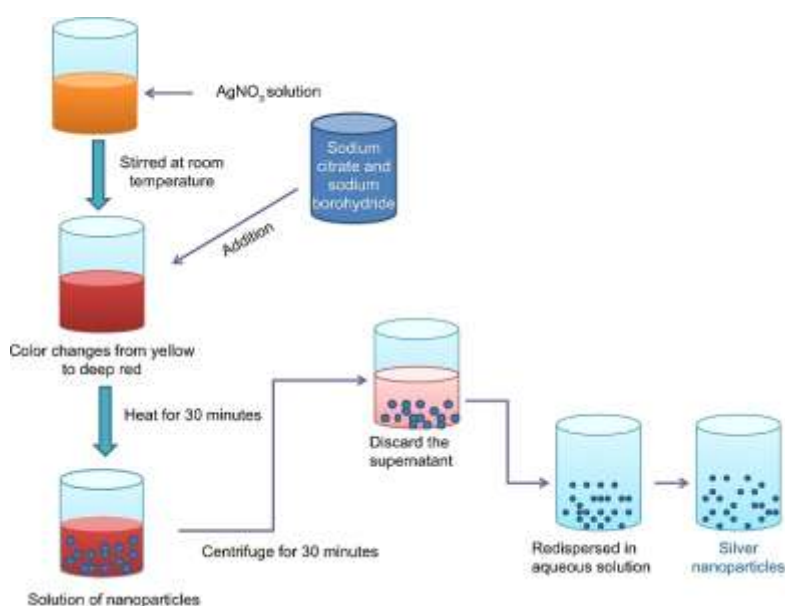
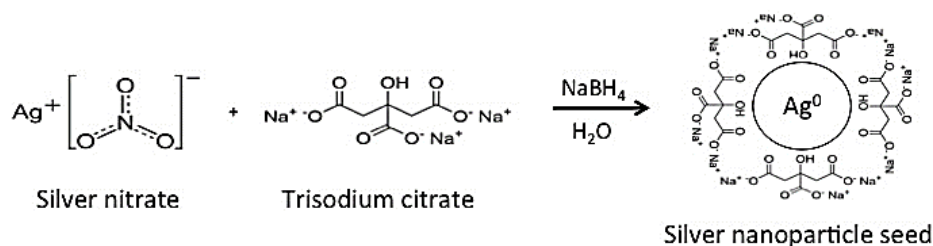
Figure 1 Possible interaction pathways of silver-containing compounds with bacterial cells.

The application of silver nanoparticles on different textile materials has emerged as a burgeoning area of research in the field of textile and polymer sciences. Silver nanomaterial's offer unique properties such as large surface area, surface plasma resonance, excellent antimicrobial activity. With these properties, novel shades of elegant hue and tune, and excellent antimicrobial activities on different textile materials such as cotton, wool, silk, nylon, polyester, and polyamide have been achieved. In view of these facts, this review outlines recent advances in the use of silver nanomaterials as coloring and antimicrobial finishing agents for different natural and synthetic textile materials.

2. Different synthesis methods of silver nanoparticles

Several methods have been developed to synthesize colloidal metal particles.[44-46] These are precipitation from homogeneous solutions by using appropriate reducing agents,[47, 48] seeded growth,[49] reverse micelles,[50, 51] and electrochemical[52] and sonoelectrochemical [53] techniques. Among these, precipitation in aqueous or nonaqueous media is the most commonly used because it is easy, cheap, and versatile shown in figure 2. The precipitation technique offers many possibilities to control the particle characteristics by changing the experimental parameters, such as reactant concentrations, temperature, pH, reducing agents, and stabilizers.[44, 54, 55] Furthermore, it is also possible to synthesize composite particles and alloys.[56-58] Because of the high electropositive

character of silver (+0.799 V[59]), various reducing agents[44, 60] including free radicals, sodium borohydride (NaBH₄),[61] citrate or ethylenediaminetetraacetic acid (EDTA),[62] and ethanol[63] can be used.



3. Silver nanoparticles as colorants

Silver nanoparticles (AgNPs) colloidal solution was prepared with different colors including yellow, red, green, blue and grey [64-71] depending on their shape. In acidic medium, the preparation of silver nanoparticles by utilizing cellulose as reducing agent produced grey color[70]. The yellowish color is corresponding to the spherical AgNPs which was easily produced by using carbohydrate materials as reducing agents [64, 65, 68]. The triangular silver nanoplates and silver nanoprism have been obtained by several researchers with blue color, showing three absorbance beaks at 350, 450–500 and at 700–800 nm [72-75]. Also, the silver nanodisc colloidal solution exhibited three absorbance beaks at 350, 400 nm and the maximum beak at 500–650 nm. These three beaks are contributing to the red color [73, 76]. However, silver nanorods or nanoplates colloids had a greenish color [39, 73]. Silver nanoparticles are endowed with unique localized surface plasmon resonance property (LSPR), by which they exhibit colors.[63] The remarkable relationship between the morphology of silver nanoparticles and their color is proving to be very helpful for their use in different textile finishing applications.[77] It is worthy to note that control on the morphology of AgNps is a promising way to tailor the LSPR band and effectively tune the color of silver nanoparticles. This has recently motivated research activities to directly employ silver nanoparticles in the dyeing of cotton; silk, and wool.[78, 79]

Furthermore natural fibers as already mentioned can be easily colonized by high numbers of microbial pathogens, including both moulds and bacteria therefore, are potentially responsible for the nosocomial infections.[80] Silver nanoparticles are nowadays considered as next generation antimicrobial agents for functional finishing of different textile materials. Various finishing technologies such as padding, rinsing, sol-gel, sputtering, and printing have been developed to incorporate silver nanoparticles onto different natural fiber/fabric surfaces.[81]

4. Coloration of Natural fibers with Ag Nanoparticles

4.1 Cotton

Considering the application of silver nanoparticles to different textile materials cellulosic fibers are most extensively studied because of their breathable, soft, comfort and other outstanding attributes. Some researchers recently reported the possibility of utilizing localized surface plasmon resonance property of silver nanoparticles for enhancement of the color strength of cotton based fabrics and their antimicrobial properties. Chattopadhyay *et al*[82] analyzed the dyeing property of natural fabrics including cotton with direct dyes pre-treated with silver nano colloids synthesized by the reduction of silver nitrate, and found improvement in color strength and fastness properties. Tang *et al*[83] used this property to study the coloration of cotton using anisotropic silver nanoparticles with different colors. At low temperature, they assembled silver nanoparticles on cotton by linking poly (diallyldimethylammoniumchloride) to produce colorful shades with acceptable color and fastness properties. Solution dipping method was applied by Wu *et al*[84] to produce colorful shades with satisfactory fastness and durable antibacterial properties on cotton. They reported that the treatment of cotton with branched poly (ethylenimine) (PEI), silver nanoparticles with different colors, and fluorinated-decyl polyhedral oligomeric silsesquioxane led to the production of cotton with durable antibacterial activity against *E. coli* and *B. subtilis* and self-healing property. The deposition of silver nanoparticles on PEI-doped cotton indicated that primary, secondary, and tertiary amino groups of PEI and functional groups of the silver nanoparticles were involved in electrostatic and hydrogen bonding interactions. The TEM images, UV spectra and different beautiful and elegant hues on cotton fabrics produced with silver nanoparticles are shown in Figure 3-5.

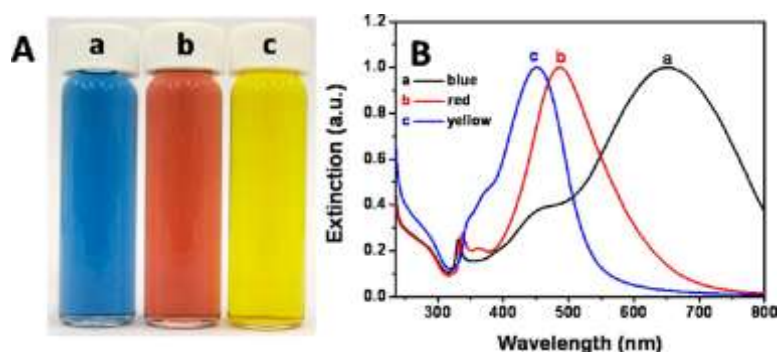


Figure 3 (A) Photograph and (B) extinction spectra of (a) blue, (b) red, and (c) yellow silver nanoparticle solutions.

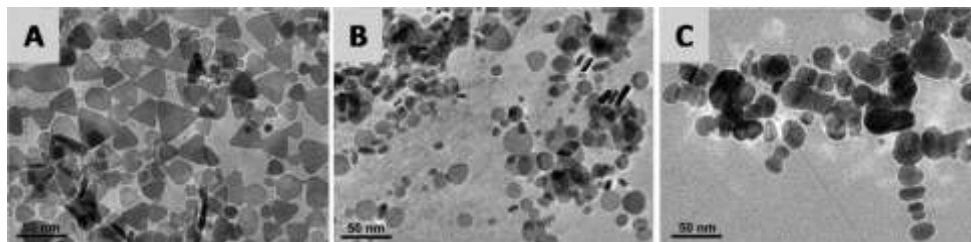


Figure 4 TEM images of (A) blue, (B) red, and (C) yellow silver nanoparticles.

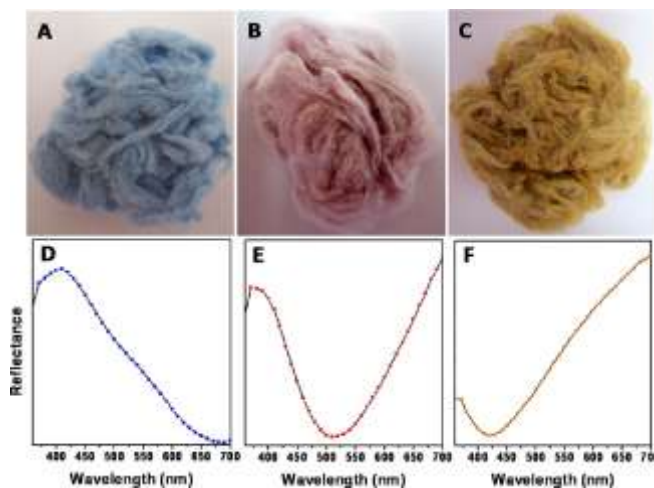


Figure 5 (A–C) Cotton fibers treated with (A) blue, (B) red, and (C) yellow silver nanoparticles. (D–F) Reflectance spectra of the silver nanoparticle treated cotton fibers corresponding to A–C, respectively.

Likewise Emam and colleagues[85] reported two solvent less techniques namely sorption and padding to deposit silver nanoparticles onto cotton in order to produce colored and multifunctional cotton. It was shown that sorption technique was more efficient to deposit 69.3–6094.8 mg/kg of silver than padding which showed only 33.8–609.3 mg/kg silver content on the cotton. Increase in the concentration of AgNO₃ resulted in the color change of cotton from gray-to reddish yellow and improvement in the color strength values. Illumination of the Assembly of Silver Nanoparticles on the Surface of Cotton Fiber are shown in figure 6.

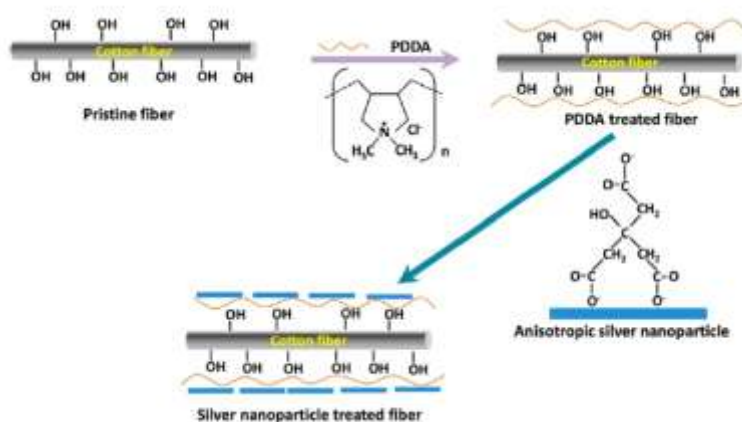


Figure 6 Illustration of the Assembly of Silver Nanoparticles on the Surface of Cotton Fiber

Cotton fabrics treated with these silver nanoparticles show excellent antibacterial activity against *E. coli*. Ilic *et al*[86] applied colloidal silver nanoparticles fabricated without adding any stabilizer on cotton to study the color change and antimicrobial activity of AgNps against *E. coli*, *S. aureus* and fungus *Candida albicans*. They observed that silver nanoparticles from 50 ppm colloid solution had more laundering durability than 10ppm solution. Thanh *et al*[87] used the polyol method involving microwave heating to fabricate nano-sized silver colloid for application on cotton. They found that the presence of 758 mg/kg of silver nanoparticles on cotton is highly effective in killing of bacterial pathogens. Raza *et al*[88] introduced an enzymatic pretreatment with aqzaym SDL (an amylase), scourzyme L (a pectinase) and celluloft L (a cellulase) enzymes in order to fabricate silver nanoparticles via one spot synthetic route on the surface of cotton. Several research studies have been carried out over the last few years dealing with the use of natural products for the synthesis of silver nanoparticles. To decrease the cost involved in synthesis of AgNps, Satishkumar *et al*[89] investigated reduction of silver ions to nano-sized particles using chemical compounds present in *Curcuma longa* tuber powder and extract for their application to cotton fabrics. They found that cotton fabrics treated with silver nanoparticles in the presence of polyvinylidene fluoride (PVDF) resulted in good wash durability of the claimed antimicrobial activity on cotton.

4.2 Wool

Wool is complex in structure and essentially composed of three tissues, cuticle, cortex and the medulla.[90] It contains free carboxylic acid and amino groups which have been employed to cross link via covalent bonds or through secondary interactions such as hydrogen bonds, van der Waals forces, and dipole–dipole interactions with different textile finishing agents currently used in textile industries.[91] Scientists have in recent years directed intense research towards silver nanoparticles as new functional agents for wool based fabrics.[92] The keratin proteins of wool have been employed to fabricate silver nanoparticles for their application as antibacterial agents. Lu and Cui *et al*[93] explored the role of keratin extracted from wool in the formation of stable silver nanoparticles. They used UV–Vis and Fourier transform infrared spectroscopy methods to study the effect of keratin concentration, and possible modes of interaction between silver core and capping agent, respectively. They found that this method is highly facile and cost-effective to produce silver nanoparticles which are stable in aqueous medium up to three months. Cell membrane complex in wool and other low sulphur regions are identified as main regions of entry for inorganic and polymer based nanoparticles.[94] Osorio and co-workers [95] reported that in-situ deposition of silver nanoparticles on wool can be more efficiently done in an aqueous system compared to ethanolic system. Perumalraj[96] reported the dyeing and fastness properties of wool fibers in the presence and absence of silver nanocolloids with acid and direct dyes. Their results showed that silver nanocolloids can be suitably applied on wool fibers to produce shades having good color strength and improved fastness towards light and washing. Digital photograph, extinction spectra and Photos of the wool fabrics colored by different silver NPs are shown in figure 7 and 8. Raja *et al et al*[97] reported the synthesis of silver nanoparticle-polyvinyl pyrrolidone composite in powder form containing silver particles of size 50-60nm using sono-chemical method, and studied their antimicrobial activity on textile substrates including wool. The treated wool displayed good antibacterial activity *S. aureus*, *E. coli* and *P. aeruginosa* with a reduction percentage of 100%, 97% and 99% respectively[98]. Ki and co-workers[79] synthesized sulphur nano-silver colloidal solution with an average size of 4.2 nm and applied it to wool based textiles for antibacterial activity against Gram-positive *S. aureus* and Gram-negative *K.*

pneumonia. In addition to antibacterial activity, they claimed that sulphur nano-silver colloid solution also imparts mothproofing, antibiotic, and antistatic property to wool. Recently silver in nano form has also been utilized as a coloring agent to develop novel and beautiful hues on wool materials.

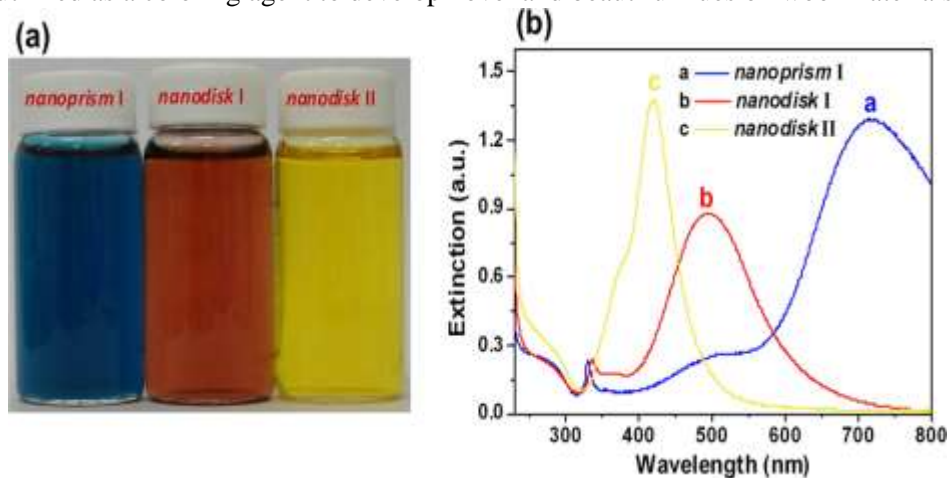


Figure 7 (a) Digital photograph and (b) extinction spectra of the obtained silver NP solutions with different colors (blue, red and yellow). [72]

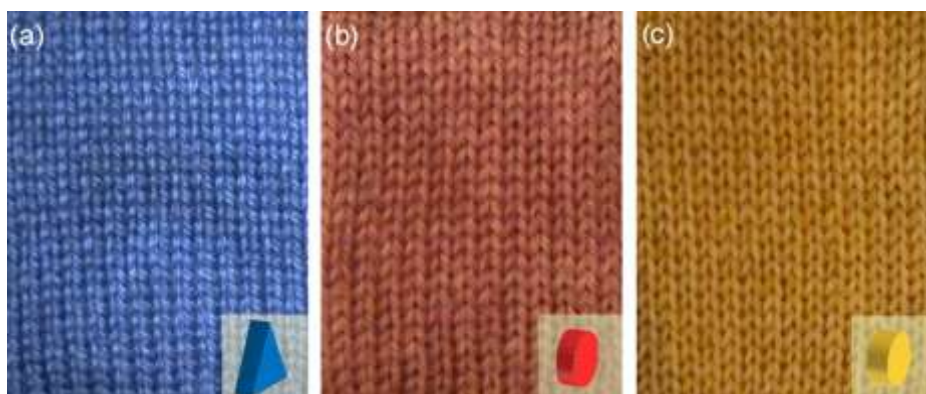


Figure 8 Photos of the wool fabrics colored by different silver NPs: (a) nanoprism I, (b) nanodisk I, and (c) nanodisk II.

Kelly and Johnston[99] used silver nanoparticles with LSPR properties to color merino wool fibers and fabrics. They synthesized silver nanoparticles through the reduction of silver ions in solution by trisodium citrate in the presence of merino wool fibers or fabrics and proposed that the silver nanoparticles simultaneously bind to the amino acids of the keratin protein in the wool fibers, using trisodium citrate as the linker. Illumination of the coloration of wool fiber by using different silver NPs are described in figure 9. SEM images of wool fibers colored by silver NPs are shown in figure 10 and 11. Falletta et al[100] prepared the few-nanometre-sized silver nanoparticles by the reduction of silver nitrate in the presence of poly(acrylates) of different molecular weights through sodium borohydride reducing agent or by irradiation with UV light for the antibacterial finishing of wool and other textile substrates. They observed that the wool fabrics treated with synthesized silver nanosols exhibited good antimicrobial inhibition against *S. aureus*, *S. epidermidis*, *P. aeruginosa*, and *C. albicans* pathogens.. To enhance the diffusion of AgNPs into the wool, they employed lecithin which is a biological lipid and reported that increasing the concentration of lecithin decreased the release of nano silver thereby

reducing cytotoxicity. The enhancement in diffusion of silver ions into wool was ascribed to electrostatic interaction between positively charged silver ions and negatively charged carboxyl groups. Further, the treated wool with nanosilver/lecithin combination displayed good antibacterial activity.

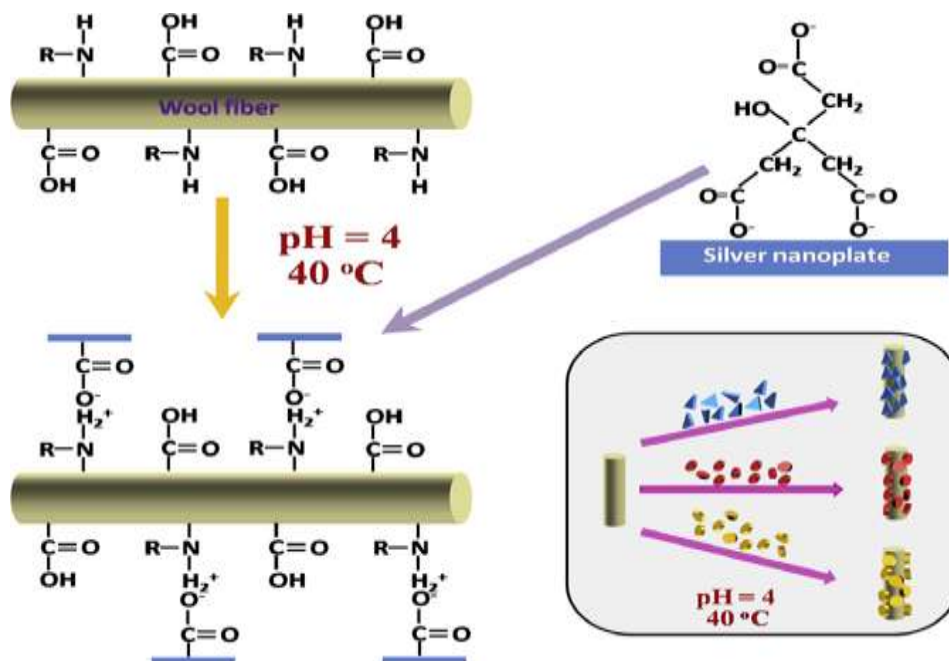


Figure 9 Illumination of the coloration of wool fiber by using different silver NPs

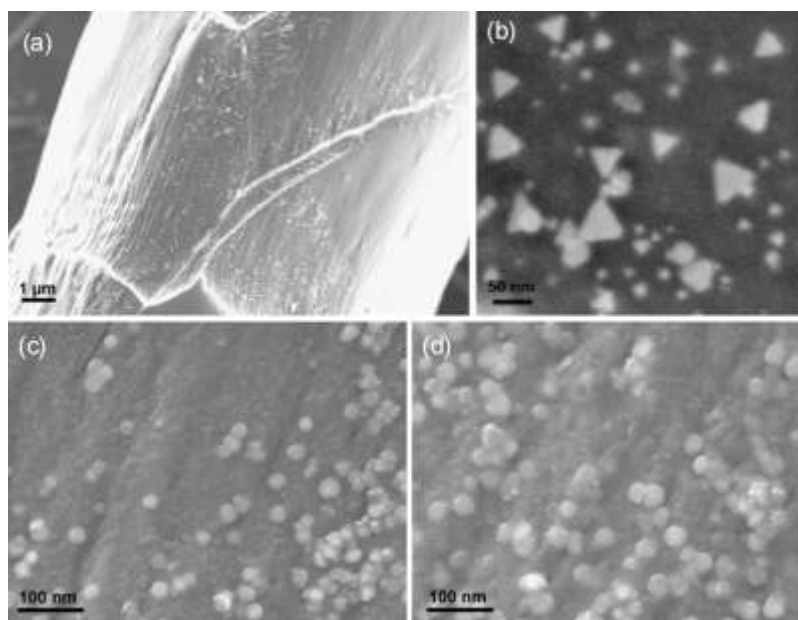


Figure 10 SEM images of wool fibers colored by silver NPs: (a) and (b) nanoprism I, (c) nanodisk I, and (d) nanodisk II.

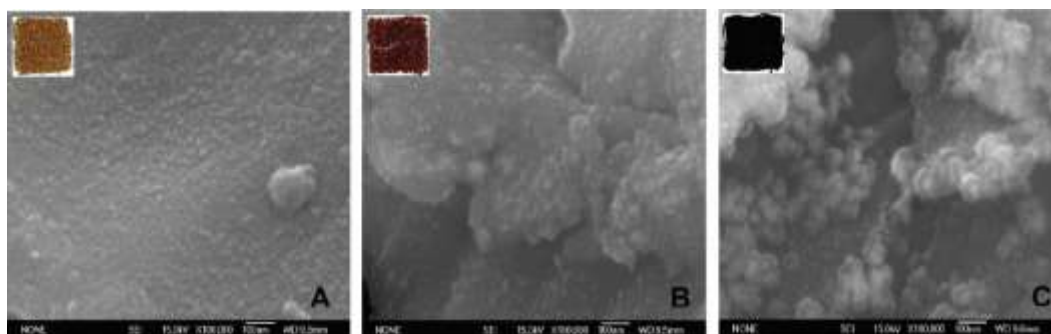


Figure 11 SEM images of silver nanoparticle merino wool composites prepared with (A) 20 μL of 1% TSC, (B) 10 μL of 10% TSC, and (C) 50 μL of 10% TSC. The scale bar depicts 100 nm[72].

4.3 Silk

Silk structure is simpler and similar to wool but contain amino acids having smaller pendant groups than those found in wool. Owing to their excellent mechanical properties, biodegradability, softness, smoothness, luster, Comfortableness, and hygroscopicity, silk fibres are extensively used in a variety of application fields.[101] anomaterials and particularly silver is used by researchers nowadays to obtain multifunctional effects on silk protein. Numerous research investigations have been carried over the past few decades to synthesize silver nanoparticles of diverse morphologies for their use in coloring and antimicrobial finishing of silk fibers and fabrics.[82] photograph of the synthesized silver nanoparticle solutions, extinction spectra of the silver nanoparticles, TEM images of silver nanoparticles with different colors, SEM images of the silk fibers treated with silver nanoprisms, photograph of the silk fibers colored by corresponding silver nanoparticles are illustrated in figure12-15. Chemical reduction of silver nitrate using hydrazine and glucose as reducing agents was examined by Gulrajani et al.[102] In their research work, synthesized silver nanoparticles having average size of 10 and 35nm were applied on the silk fabrics to obtain antibacterial activity against gram positive *S. aureus*. It was observed that the silk fabrics treated with 40 ppm and 60ppm silver hydrosols produced at 5°C and 60°C had 100% activity against tested microorganism. Vankar and Shukla[103] reported the use of Citrus limon extract as reducing and encapsulating cage for the reduction of Ag^+ ion to Ago. The synthesized silver nanoparticles were used for the antibacterial modification of silk against *Fusarium oxysporum* and *Alternaria brassicicola*. Tang et al[104] carried out the coloration of silk using different morphologies of anisotropic silver nanoparticles and obtained colorful shades with good fastness properties. The silk fabrics coated with silver nanoparticles were also assessed for antibacterial activity against *E. coli*. They concluded that the treatment with silver nanoparticles does not cause any damage to silk fabric and could be a promising way to achieve a range of colorful shades as well as antibacterial finishing of silk. Zhang et al[105] in a research investigation claimed that in-situ formation of silver nanoparticles produced by their method involving the use of multi-amino compound which acts as reducing agent results in the development of antibacterial silver fabrics. They observed that the antimicrobial activity of treated silk fabric against *S. aureus* and *E. coli* was retained for more than 50 washings.

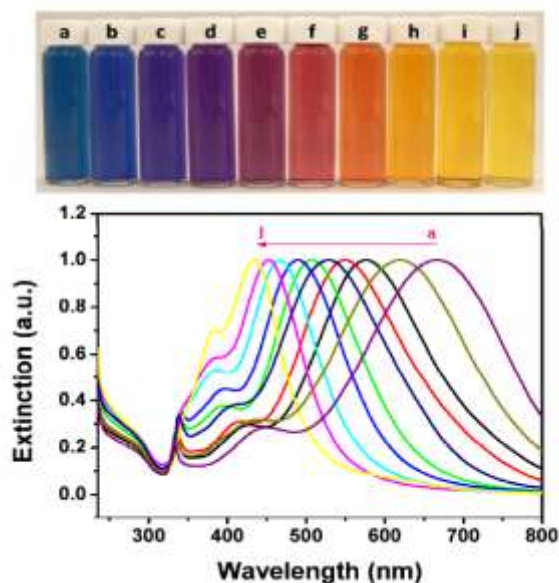


Figure 12 Upper: photograph of the synthesized silver nanoparticle solutions with different colors. Bottom: extinction spectra of the silver nanoparticles corresponding to the above solutions.

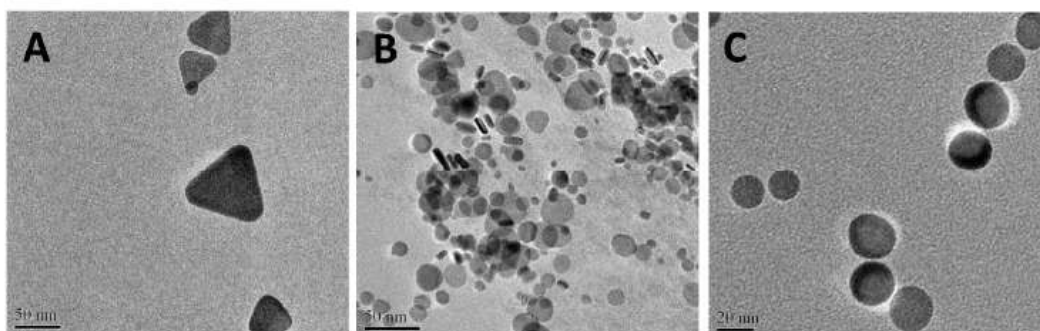


Figure 13 TEM images of silver nanoparticles with different colors: (A) blue, (B) red, and (C) yellow.

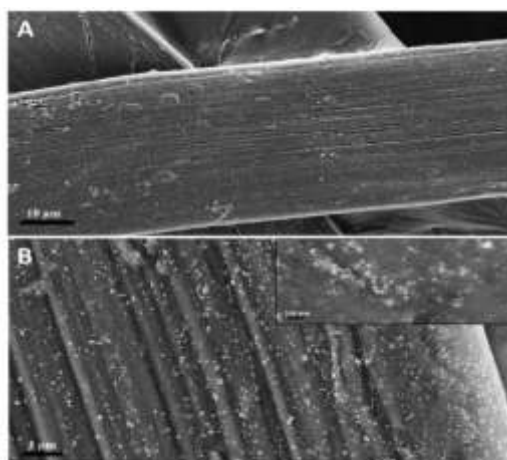


Figure 14 (A) SEM image and (B) enlarged SEM images of the silk fibers treated with silver nanoprisms.

Several latest approaches such as UV and ultrasound assisted, gamma irradiation, steam, layer-by-layer assembly and electro less silver plating methods have been studied so far to realize in-situ fabrication of silver nanoparticles on silk. Potiyaraj *et al*[106] synthesized silver chloride nanocrystals by dipping of silk fibers in alternate solutions of AgNO₃ and NaCl, and revealed that 100nm AgCl nanocrystals are formed after 20 alternate dipping steps. They proposed that the treated silk fiber could be used as an antibacterial agent. Abbasi and Morsali *et al*[107] synthesized silver iodide nanoparticles on silk fibre in the presence of potassium iodide and silver nitrate under ultrasound irradiation with sequential dipping method. In a subsequent research study, Abbasi and Morsali[108] studied the role of ethylene glycol as a reduction and protecting reagent in the formation of crystalline silver nanoparticles on silk yarn, and discovered that using power ultrasound technique yields smaller sized nano particles. Lu *et al*[109] used ultraviolet light (UV)-assisted method to fabricate silver nanoparticles on degummed silk fibers and investigated antibacterial properties of treated silk using growth curve, zone of inhibition and FITC/PI dual staining assays against *S. aureus* and *E. coli*. XRD patterns revealed that UV irradiation and AgNPs immobilization on degummed silk fibers did not caused any damage to the structure of silk fibre. As could be predicted, in-situ produced crystalline silver nanoparticles were found highly active against both Gram-positive and Gram-negative pathogens. Yu *et al*[110] utilized polydopamine as a reducing agent to produce in-situ silver nanoparticles with face centered cubic crystalline structures for antibacterial finishing of silk.

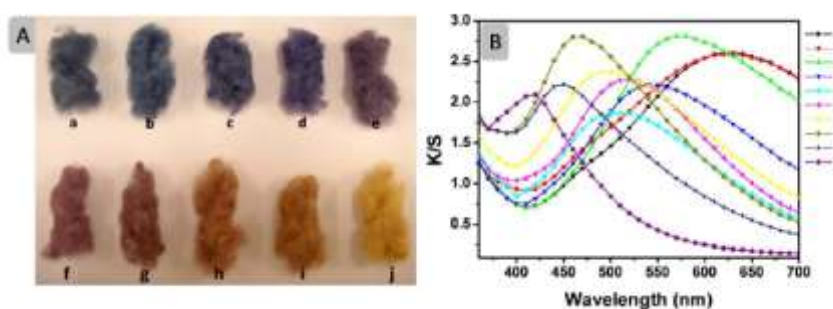


Figure 15 (A) Photograph of the silk fibers colored by corresponding silver nanoparticles in Figure 1. (B) K/S curves of corresponding silk fibers colored by silver nanoparticles.

The silk fibers coated with silver nanoparticles exhibited high antibacterial activity against *E. coli* and *S. aureus*. Wang *et al*[111] assessed the in-situ Ag nanocluster formation on silk fibre using ultraviolet light-induced reduction method and realized the production of luminescent fibre with emission band at about 550nm as well as good antibacterial activity of the treated fibre against *E. coli* and *S. aureus*. Zhang *et al*[112] synthesized in-situ nano silver particles using polyamide polymer by steam method and then applied on silk to obtain the antibacterial properties. The deposition of silver nanoparticles on silk had shown high activity against *S. aureus* and *E. coli*. Durability to the antimicrobial activity against both the bacteria was maintained up to 30 consecutive home washing cycles. Chang *et al*[113] have described strong antibacterial property of silk fibers obtained by gamma ray irradiation method, based on in-situ formation of 20nm silver nanoparticles on the fibre surface.

5. Coloration of man-made fibre with Ag Nanoparticles

5.1 Viscose

The coloration technique depends on the formation of in situ AgNPs in viscose fibers. Schematic diagram (Fig. 16) shows the mechanism of coloration technique which can be described in points as follows: (1) Immersion of cellulosic fibers in NaOH, caused swelling of cellulose fibers [114] which in turn helped in distributing silver ions (Ag^+) inside the cellulosic matrix and hence improving the color homogeneity and fastness of the resultant fibers. In the swelling step, non-active cellulose transformed to alkali activated cellulose (Cell-COONa). (2) Besides, the alkali pretreatment raised the pH value to ≈ 12 which plays an important role in the reduction of Ag^+ to AgO. (3) When silver nitrate added to cellulose in alkaline solution, Ag^+ diffused well inside the swollen cellulose. The ion exchange interaction and/or complexation between Ag^+ and functional groups of cellulose (COO-Na and OH groups) are supposed to take a place [64, 70, 115, 116]. (4) By raising the temperature to 70°C , the reducing end groups of cellulose are suggested to be more active for reducing Ag^+ to nanosized AgO inside cellulosic matrix giving the yellow color. The reduction process of Ag^+ is catalyzed by the effect of light and heating [115-117]. (5) Stabilization of the synthesized AgNPs could be related to the steric effect of the cellulosic chains. (6) Finally, the unbounded AgNPs were removed from the colored fibers by rinsing. The UV-vis spectra of the supernatant solutions by using different concentrations of silver nitrate solutions are shown in figure 17.

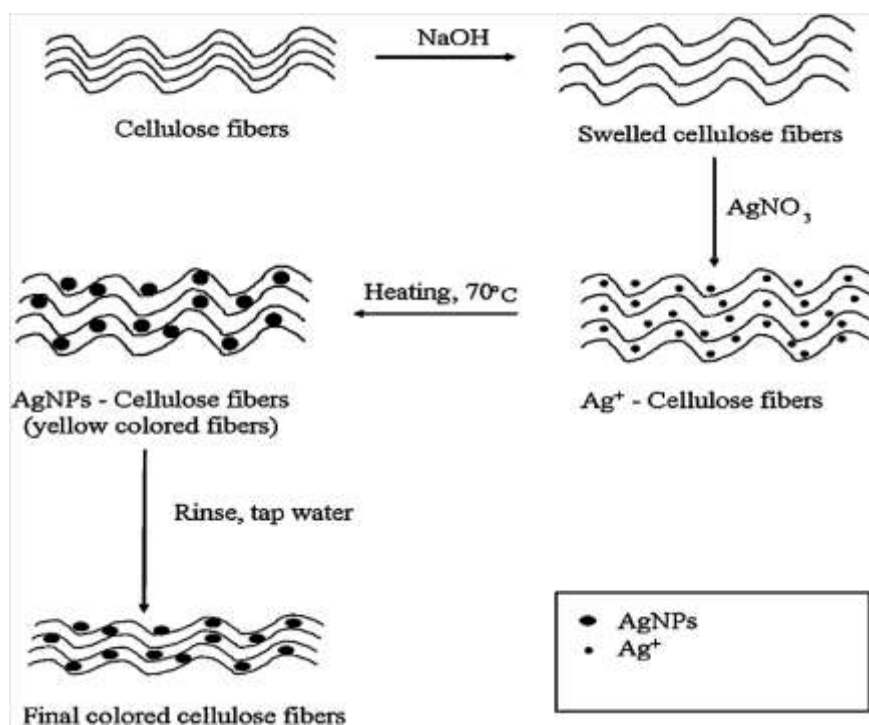


Figure 16 Schematic diagram represents the proposed coloration mechanism of viscose as cellulosic fibers by forming in situ AgNPs.

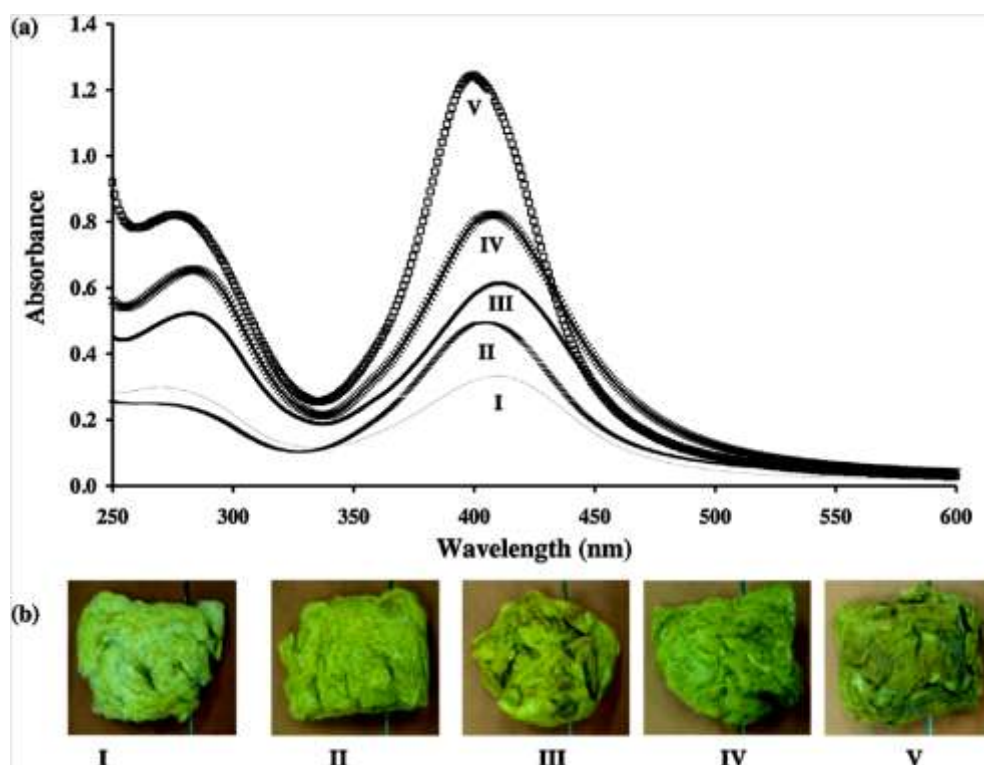


Figure 17 (a) The UV–vis spectra of the supernatant solutions by using different concentrations of silver nitrate solutions (I) 0.4 mmol/l, (II) 1 mmol/l, (III) 2 mmol/l, (IV) 4 mmol/l, (V) 8 mmol/l, after 45 min immersion time at 70°C using 1:50 M/L ratio. (b) Photographs of the corresponding treated fibers.

6. Conclusion

The work on silver nanoparticles for functional finishing of natural and synthetic textile materials is much more than any other currently available nanomaterial's. Silver in nano form has broad spectrum of antimicrobial properties towards bacteria and fungi and has become more prevalent in textile materials as antimicrobial agents in response to the rising need for safer and effective antimicrobials. A lot of more facts about silver nanoparticles are also confirmed, the surface plasma resonance property of silver nanoparticles has recently been utilized to develop colorful shades on cotton, wool, and silk. The way from hypothesis to a full mechanism of action of the silver nanomaterial's after application on textiles is a hot topic of debate among scientific community. It is worth noting that silver nanoparticles compared to other metals are considered safer antimicrobial agents due to their low toxicity for humans.

7. Future prospects

Up to now, most of the studies conducted in this realm have focused on the ex-situ and in-situ methods for production of silver nanoparticles and their application as potent antimicrobial agents on different textile materials such as cotton, wool, silk, nylon, polyester and others. Scientists have also employed over the past few years some innovative crosslinking agents and pre-treatment technologies in order to enhance the binding efficiency of deposited silver nanoparticles for long lasting antimicrobial

activity.[118] Despite a plenty of research devoted to the application of silver nanoparticles for functional finishing, there are only few studies that have demonstrated the effects of nano silver content released in waste water bath, or its contact or effects on humans and environment.[119-121] The washed out silver nanoparticles from different textile substrates may have lethal effects on both flora and fauna. To address this issue, more and more research should be carried out to highlight the side effects of silver nanoparticles on human health and ecology. This will lead to a better understanding and facilitate use of silver nanomaterials on a commercial large scale as novel colorants and antimicrobial agents for application onto different textile materials.

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