ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

ANTIMICROBIAL AND ANTIVIRAL PROPERTIES OF METAL NANOPARTICLES AND THEIR POTENTIAL USE IN TEXTILES: A REVIEW

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Abstract: *Recent global trends have put an emphasis on the importance of hygiene in all sectors including textiles. Antimicrobial and antiviral finishes are used in textiles to control bacteria, moulds, fungi and viruses on the textile substrate. Metal nanoparticles have been shown to posess antimicrobial and antiviral properties and can potentially be used in textiles for the production of fabrics with these functions. The aim of this paper is to explore the different antimicrobial and antiviral properties possessed by zinc oxide nanoparticles, titanium dioxide nanoparticles, silver nanoparticles and copper nanoparticles and their potential use in textiles. The challenges associated with these metal nanoparticles have also been assessed. Most of the metal nanoparticles studied display antibacterial properties against gram-negative Escherichia Coli and Pseudomonas Aeruginosa as well as gram-positive Staphylococcus aureus. Antiviral activities were also observed against Herpes Simplex Virus Type 1 (HSV-1), H1N1 influenza, poliovirus and foot and mouth disease. Although the metal nanoparticles showed potential for use as antimicrobial and antiviral finishes for textile substrates, environmental concerns have been raised on their use as they tend to be toxic during use and also produce a harmful washing effluent. Future studies should focus on the mitigation of the toxicity challenges associated with the use of metal nanoparticles.*

Key words: *Nanoparticles, Antimicrobial activity, Antiviral activity, Silver nanoparticles, Zinc Oxide nanoparticles*

1. INTRODUCTION

The current COVID-19 pandemic has sparked a lot of research interest in different sectors on possible ways of mitigating the spread of the virus. According to the World Health Organisation, the virus can be spread when an infected person is in close contact with other people and exhales or emits body fluids or virus-containing aerosol particles into the air. The virus can also be spread by touching surfaces that have been contaminated by the virus and then touching the mouth, nose or eyes without cleaning their hands. Textiles that consumers come into contact with on a daily basis such as clothes, bed sheets and textiles could potentially be a medium for the transmission of viruses. The global trends have therefore put an emphasis on the importance of hygiene and health in textiles, which has necessitated studies on antimicrobial and antiviral textiles. Antiviral finishes are those that reduce viruses in textile substrates. Antimicrobial textiles are used in textiles to control bacteria, moulds and fungi on the textile substrate. The use of nanomaterials has become popular in the textile industry for the incorporation of functional properties onto conventional textile materials. These properties include dirt repellency, water repellency, ultraviolet radiation, anti-odour, self-cleaning, flame retardancy, antiviral and antimicrobial properties. Inorganic finishes such as silver, magnesium, gold, titanium, copper and zinc have been used for durable antimicrobial finishes on natural, regenerated and synthestic textile materials. These metals and metal oxides have been used in nanoparticle form because of their durability to textiles, higher antimicrobial and antiviral functionality and their reduced environmental risks. Nanoparticles are materials that have all dimensions in the nanometre range, that is, less than 100nm. In textiles, the most commonly used nanoparticles are zinc oxide and silver. The aim of this paper is to explore the different antimicrobial and antiviral properties possessed by selected nanoparticles and their potential use in textiles. This paper will also assess the challenges associated with these metal nanoparticles in their use in textiles.

2. METAL AND METAL OXIDE NANOPARTICLES

2.1 Zinc Oxide Nanoparticles

Zinc metal and its oxide have special properties which include being bio-safe and hence have found application in the biomedical field. The utilization of zinc oxide in providing antimicrobial properties to cotton fabrics has been described in a study where 100% cotton plain weave substrate of 150 GSM was used. The cotton substrate was treated with zinc oxide nanoparticles (ZnO NPs) and the treated fabric recorded acceptable bacteria resistance against *staphylococcus* [1]. In another study cotton fabrics coated with ZnO NPs exhibited antibacterial effect against *staphylococcus epidermis*, *staphylococcus aureus* and *Propionibacterium acnes* with great potential for use as coatings for sport, medical and cosmetic fabrics [2]. Zinc nanoparticles have also been reported to have an acceptable efficacy against *Escherichia coli* (*E. coli*) and *sataphylococcus aureus* (*S. aureus*) bacteria. It was observed that zinc oxide nanoparticles have better antibacterial activity on gram positive (*S. aureus*) than the gram negative (*E. coli*) bacteria [3]. The efficacy and durability of the ZnO NPs on the textile substrates is affected by the treatment procedure as well as the additional reagents included in the procedure. A more durable antibacterial finish has been achieved with ZnO NPs and Gallic Acid coated fabrics which maintained efficiency even after 60 washing cycles. The enzymatic crosslinking of gallic acid resulted in the formation of a bio adhesive in which the nanoparticles were embedded thus improving the durability [4]. A single treatment process with low fabrication cost has been used in the production of zinc nanotextiles with enhanced antibacterial activity against different species of bacteria especially *K. pneumonia* [5]. Antibacterial cotton fabric has also been achieved by the single-stage in-situ growth of ZnO nanostructures on cotton fabric; the coated cotton fabrics exhibited an antibacterial efficiency towards *Pseudomonas aeruginosa* and *staphylococcus aureus* [6]. ZnO NPs have acceptable antiviral properties and these can be improved by coating with polyethylene glycol for a stronger antiviral effect against H1N1 influenza [7] and also against herpes simplex virus type 1 (HSV-1) [8]. Zinc nanoparticles have good properties such as anticancer, antioxidant, antimicrobial and have shown good antifungal activity against *Alternaria saloni* and *Slerrothum rolfi* strains. Zinc nanoparticles show good potential for use in textiles for the impartation of antimicrobial and antiviral finishes. However, as these nanoparticles will come into close contact with the skin, there is a chance that they will be absorbed into the body through skin pores and any other openings [9].

2.2 Titanium Dioxide Nanoparticles

Titanium dioxide is a material of interest because of its low-cost, non-toxicity, chemical stability and high photo-reactivity; it has been used effectively agains bacteria, viruses and fungi.

Titanium dioxide nanocomposites have demonstrated maximum bacterial inhibition against *pseudomonas aeruginosa* and antiviral activity against Newcastle virus. The nanoparticles also showed an effective antimicrobial activity against *S. aureus* and *E. coli* when applied onto knitted nylon 6.6 fabric by the layer-by-layer technique [10]. However, the main challenge with titanium dioxide is that its reactivity requires light illumination and thus its application can be limited in certain circumstances where there is limited light, for example, indoors. Therefore, titanium dioxide nanoparticles are often doped with other metals to enhance their antimicrobial properties even when used indoors. When applied onto cotton fabrics, titanium dioxide nanocrystals required the light illumination to allow for effective antimicrobial action. Significant antimicrobial effect was observed mainly against *staphylococcus aureus*. Studies have shown that polyester fabric modified by a small amout of titanium dioxide is incapable of inhibiting the growth of pathogenic bacteria due to the low photochemical activity of the coating but can inactivate gram negative bacteria when modified by metal-doped titanium oxide nanoparticles [11-12]. In another study, cotton treated with titanium dioxide/platinum nanocomposites exhibited superior antibacterial activities against both *Staphylococcus aureus* and *Escherichia coli* bacteria when compared with nano-titanium dioxide alone [13]. Apatite coated titanium dioxide when applied to cotton fabric has been shown to be effective against four types of bacteria, that is, *S. aureus*, *E. coli*, *methicillin-resistant staphylococcus aureus* and *micrococcus luteus*. Unmodified titanium dioxide and titanium dioxide modified hydroxyapatite composite have displayed strong antiviral activity against H1N1 infuenza A virus under ultraviolet light [14-15].

2.3 Silver Nanoparticles

Silver is the most commonly used inorganic finish because of its high thermal and electrical conductivity, lower contact resistance and also because it occurs in several oxidation states. Silver kills microorganisms by blocking and disengaging the intracellular proteins. Silver nanoparticle has been shown to exhibit antibacterial properties against *Escherichia coli* when applied on cotton and viscose fabrics; the treated fabrics showed good results even after washing [16]. Silver nanoparticles with protein capping have been applied onto cotton fabric and have displayed antimicrobial activities against *Candida albicans, candida parapsilosis* and *xanthomonas axonopodis*. In this study washed nanoparticles presented a more pronounced antimicrobial effect due to the lower concentration of stabilizing agents [17]. In an attempt to improve the nanoparticle adhesion, cotton fabrics were coated chemically with silver nanopartricles using polydopamine as an adhesive and then with hydrophobic polydimethylsiloxane or polyimide. The introduction of polydopamine significantly increased the bond between silver nanoparticles and cotton fibres, thereby preventing silver nanoparticles from falling off the surface. The fabric composites showed a significant antibacterial action against *staphylococcus aureus* and *escherichia coli* [18]. Silver nanoparticles have also been applied in-situ and ex-situ on cotton fabric and the study showed that the in-situ treatment resulted in fabrics with stronger antimicrobial property and durability against washing even with low concentrations of silver nitrate. There was a strong antimicrobial activity against *s. aureus* than *e. coli* for both the in-situ and ex-situ treated fabrics [19]. In another research, synthesis of silver nanoparticles was done directly on textile fabrics by use of the radiochemical process which involves the irradiation of a high-energy electron beam on an aqeous solution containing silver ions. This induces a reducing reaction that forms metallic silver nanoparticles. Textile fabrics treated with silver nanoparticles demonstrated high antibacterial activity and durability against washing regardless of the specific fabric used. The fabrics used were, cotton, rayon, polyester, polyamide (nylon 6.6), acryl, polypropylene and microfiber (polyester 80%, polyamide 20%) [20]. The antibacterial efficacy of chitosan-silver nanoparticles against *S. aureus* and *e. coli* was also observed when applied as a coating onto linen fabric. The silver nanoparticle/chitosan composites were also shown to have antiviral activity against influenza A virus. The antiviral activity of the composites increased as the amount of silver nanoparticles increased. Chitosan alone did not exhibit antiviral activity suggesting that silver nanoparticles are essential for the antiviral activity [21]. Silver nanoparticles have been eco-friendly synthesized by the electrochemical method and have inhibited non-envelop viruses at low concentrations, particularly poliovirus [22]. Numerous studies have agreed that silver nanoparticles possess antimicrobial and antiviral properties with several examples of how they could possibly be applied in textiles. The issue of toxicity of metal oxide nanoparticles has been the subject of much systematic investigation with many studies highlighting the challenge of the silver particles being released into the washing or rinsing effluent and subsequently into waste water disposal sites. These silver particles can inhibit the nitrification of waste water and hence reduce the effectiveness of water treatment [23]. Another challenge is that if they make their way to the aquatic systems, they result in oxidative stresses in marime organisms form the dissolution of the metal ions thus leading to chronic health impacts [24].

2.4 Copper nanoparticles

Copper nanoparticles are low-cost, durable and are effective nanoparticles. They have shown good antimicrobial properties against *E. coli* and *S. aureus* when prepared by electroless deposition in water; *S. aureus* was more susceptible to the copper nanoparticles than *E. coli* [25]. Novel antimicrobial nanocomposite material based on polypropylene (PP) non-woven fabric, biopolymer alginate and copper oxide nanoparticles have been prepared in a previous study. In order to introduce polar groups onto the surface of PP fibres necessary for bindimg of alginate, nonwoven fabric was activated by corona discharge. All fabricated nanocomposites provided excellent antimicrobial activity against gram-negative bacteria *E. coli*, gram-positive bacteria *S. aureus* and yeast *C. albicans* [26]. Copper nanoparticles significantly inhibit herpes simplex virus type 1 (HSV-1) infection. The inhibition occurs when copper oxide nanoparticles are added after virus adsorption to the cells [27]. However, these nanoparticles have shown toxicity towards human organs. An in vitro skin toxicity study of these nanoparticles showed that metal oxide ions released from coated fabrics could affect the epidermal tissue and the underlying dermal cells upon trans-epidermal permeation [11].

3. CONCLUSIONS

A review has been done to assess the antiviral and antimicrobial properties of metal and metal oxide nanoparticles. Most of the reviewed work does not examine how the presence of nanoparticles on the textile substrates alters other properties such as comfort, aesthetics and the physicochemical properties. Although the studied nanoparticles have been shown to have the antiviral and antimicrobial properties, some have not been tested on textile fabrics. It is important to determine their efficacy when applied onto textile fabrics. Environmental concerns have also been raised on the use of metal nanoparticles for multifunctional textile finishes as they tend to be toxic to human organs including the brain, the lungs, the liver and the reproductive organs. They may also be detrimental to the environment during and after use. It is therefore important to curb the toxicity challenges associated with the use of these metal oxide nanoparticles, either by producing greener nanoparticles or by finding ways of effectively treating the effluent produced from the nanoparticles. Despite the challenges, results have shown significant antimicrobial properties of the selected nanoparticles against gram-negative *Escherichia Coli* and *Pseudomonas Aeruginosa* as well as gram-positive *Staphylococcus aureus*. Antiviral activities were also observed against *Herpes* Simplex Virus Type 1 (HSV-1), H1N1 influenza, poliovirus and foot and mouth disease. Given all the information, and all safety and toxicity concerns being understood and considered; these nanoparticles can be used in industries where antimicrobial and antiviral properties are of importance such as the health sector and the hospitality sector.

ACKNOWLEDGEMENTS

The authors would like to thank the African Centre of Excellence (II) in Phytochemicals, Textile and Renewable Energy (ACE II-PTRE) for the scholarship to undertake PhD studies at Moi University.

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