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Nanoparticles As Antibacterial Agents for Textile Finishing

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Abstract

Many synthetic compounds have been applied to impart antimicrobial properties to fabrics. In this review, the types of Nanomaterials in particular nanoparticles of inorganic metals and metal oxides are extensively used to functionalize natural, synthetic and regenerated polymers because of their effective antibacterial activity against different bacterial strains. The antibacterial activity of contact active surfaces is mainly due to its topography. If the surface has nano roughness like presence of nanorods, nanoparticles or any other nanostructure, the attaching bacteria on this surface will be killed due to penetration of these structures into membranes which leads to its disintegration. This mechanism is valid for all type of nanostructures whether they are inherently antibacterial or not. Like surface structures of many butterflies are not inherently antibacterial but their morphologies make them antibacterial. antimicrobial coating treatments on textiles, such as copper nanoparticles (CNPs) and silver nanoparticles (AgNPs) formed on plant extracts, chitosan and green synthesis, with a lower environmental impact but unaltered premium antimicrobial performance and improved durability.

Keywords: Antimicrobial finishing; nanoparticles, antimicrobial compounds.

Introduction

Nanoparticles (NPs), often referred to as invisible particulate substances with a diameter ranging from 1-100 nm (nm) are of paramount relevance in the modern science The large surface area to volume ratio of nanoparticles made them a unique delivery and antimicrobial agents in many respects. Over the past few decades, nanoparticles have been used for human welfare in different fields. In recent time an intense scientific exploration is ongoing on nanoparticles due to its potential applications in various fields including medical science, drug delivery, electronics optics, agriculture, waste water treatment, as sensor support. The prospective applications of NPs in various fields are premised on the nanoparticle's unique characteristics such as its shape, charge, size, high ratio of surface area to mass and, high reactivity. This has drawn the attention of many individual. Gold, silver, platinum, and other oxide nanoparticles have been extensively used in the field of nano-biomedicine for their distinctive properties. Infectious diseases are a set of diseases or disorders caused by pathogenic microbes (bacteria, viruses, fungi, protozoa, parasites) that directly affect human health. In recent times, infectious diseases have become a great burden on the world economy as well as on public health. Various health issues including Chronic obstructive pulmonary disease (COPD), meningitis, human immunodeficiency virus (HIV), inflammatory bowel disease (IBD), severe acute respiratory syndrome (SARS), H5N1, trichomoniasis, pneumocystis pneumonia is generally caused by microbes which cause death to millions of people around the world annually. However, for the treatment of these infections, antibiotics are often the first choice. Antibiotics significantly inhibit the presence of different microbes and reduce the associated signs and symptoms. But microbes' growing resistance against these antibiotics coupled with the abuse of drugs as well as the release of Commercial opportunities abound for antimicrobial fabrics whenever it is about controlling the spread of infectious microorganisms.

In the last few decades, newly developed antibacterial textiles have been gaining increasing attention. The use of antimicrobial textiles can help control the growth of or kill pathogens mentioned previously and limit the spread of infections through textiles.

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Various methods can be used to apply antimicrobial agents to textiles. The bonding depends on the chemistry between the antimicrobial agent and the textile . In consequence, there has been extensive research in recent years in this area. Statistics demonstrated an increasing demand, with approximately 30,000 tons of antimicrobial textiles being produced in Western Europe and 100,000 tons worldwide in the year 2000. Specifically, between 2001 and 2005, the production increased by over 15% annually in Western Europe, revealing the rapidly developing sector of this textile market . Socks, shoe linings, sportswear and lingerie account for approximately 85% of the total antimicrobial textile production.

Furthermore, a large market for antibacterial fabrics in air filters, wallpapers, outdoor fabrics and medical fabrics has recently emerged.

Antibacterial fabrics prevent the growth and dissemination of such bacteria, reassuring both doctors and patients that they stay safe from infections in hospitals, where sterilization is important. Freshness and personal hygiene are of the greatest importance in the hospitality sector, making antibacterial fabrics of particular importance.

Textiles, such as underwear, home textiles, children's clothing, medical textiles and activewear, are in close contact with human skin and are likely to be contaminated with dead human skin. Dirt from the environment, perspiration and other human skin, are nutrient sources for microorganisms. Therefore, antimicrobial fabrics ensure freshness and improved performance for users.

Advantages Of Nanoparticles (Nps)

Although nanoparticles (NPs) can be synthesized by both chemical and physical methods, the biological method of using living cells is favorable, owing to its easier, safer, cleaner, eco-friendly and cost-effective results, as no high temperature or pressure is needed. Additionally, no hazardous or toxic materials are required, and there is no need for external reducing, capping and stabilizing agents. Species as yeast, bacteria, fungi, algae, actinomycetes and plant extracts are often used to produce green NPs with variable shape, size and stability and can be applied in the field of food and textile industries.

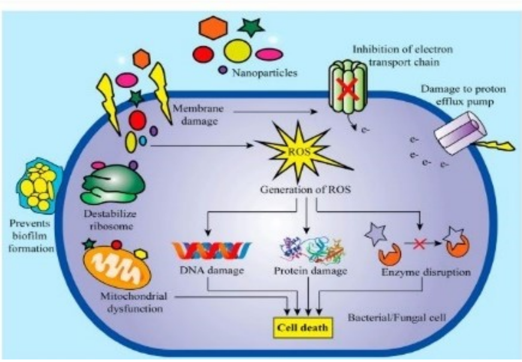

Figure 1

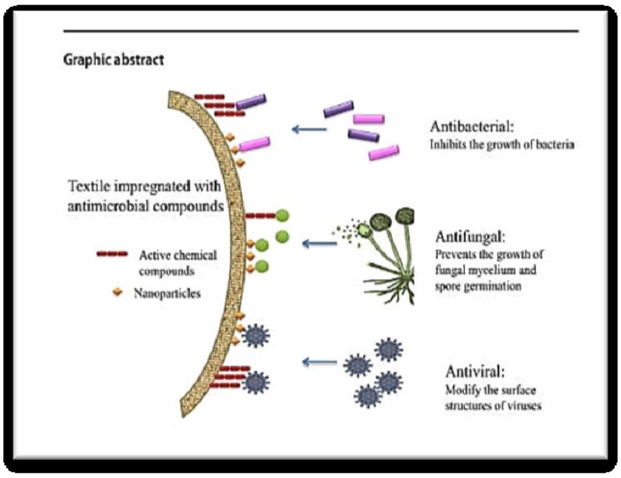

Figure 2

Nano and Nano-Materials

The word "nano" refers to a length dimension of about 10–9 m. NMs, a product of nanotechnology, are the study of the area of engineering where materials exhibit unusual characteristics that result in amazing applications. Due to the need for practical and long-lasting apparel, NMs have experienced extraordinary growth in the textile industry over the past few decades. NMs have made significant advancements in nano-finishing, the creation of nano coatings and nanofibers on textile surfaces, and the creation of nano-composites for a variety of uses in functional or high performance textiles. These materials have revolutionized engineering research since their discovery. They are particularly helpful for development since they can alter things at the application level, which aids in creating a society that can last.

Application of nanoparticles in bacterial infections:

The development and reproduction of microbes can take place in textile fabrics. Natural fibers' chemical components provide nourishment to bacteria and promote their growth. The development of microbes in textiles can lead to various issues,including unbearable odors, decreased fabric strength, stains, and health problems for the wearer. As a result, it's critical to impart an antibacterial effect to the textile material. Textiles have frequently been treated with antibacterial agents . Inorganic materials, such as metal oxides and metals, have drawn more attention in the last ten years due to their capacity to withstand difficult processing conditions .

Metal oxides, for example TiO_2, ZnO, MgO, and CaO are inorganic materials. They are considered stable in hostile process conditions moreover they are also frequently considered as secure materials for humans as well as animals .

TiO_2 is better than other titanium compounds because it works better at keeping infections away

.According to washing durability studies, fabrics treated with ZnO nano-particles can maintain a relatively lengthy antibacterial activity for up to 10 washes

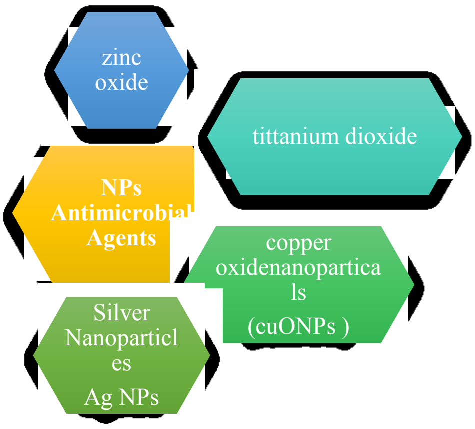

Figure 3

Examples of Nanoparticles (Diameter)

Chitosan nanoparticles (40 nm).
Silver nanoparticles (7 nm).
Copper nanoparticles (10 nm)
Zinc oxide nanoparticles (30 nm)
Copper oxide nanoparticles (20nm)
CaO nanoparticles (16 nm)
Fluorescent Ag nanoparticles (nAg-Fs), 1.5 nm
Magnetic Iron oxide nanoparticles (50–110 nm)
Magnesium oxide nanoparticles(10.28 nm).

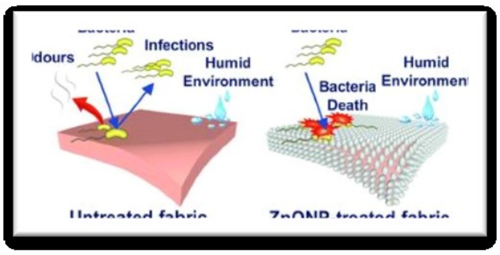

Figure 4

Currently NPs of silver [1]titanium dioxide, silver bromide, zinc oxide], gallium, gold, carbon nanotubes and copper oxide are being used as biocide releasing antibacterial agents (Fig. 10) that kill bacteria before their access to the surface.

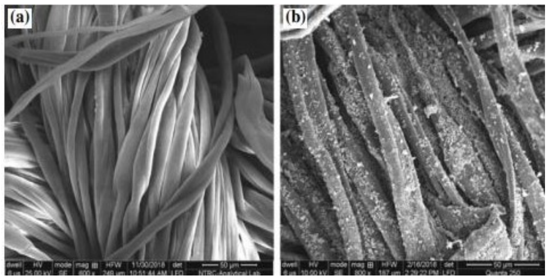

Figure 5

The Mechanism of Nanoparticles Antibacterial Activity

Polymer matrices are a suitable base for antimicrobic nanocomposites, and CNPs can be efficiently implemented as a filler. When placed in an aquatic environment, water that contains dissolved oxygen allows the release of cupric ions (Cu2+), which diffuse through the nanocomposite and are released .

The matrix selection is very important, as different polymers can yield different properties. Poly (vinyl methyl ketone) (PVMK) and polyvinyl chloride (PVC) yield more cupric ions than poly (vinylidene fluoride) (PVDF). Polyethylene (CNP) displays exceptional bioactive properties. It is noticed that the production of (Cu2+) is much stronger during the first month of incubation, and it eventually ebbs away. Another polymer that was used is polypropylene for antimicrobial plastic production. Two different nanocomposites were created using the melt blending method. One is with copper metal nanoparticles and the other is with copper oxide nanoparticles. It was concluded that copper oxide nanoparticles had a better antimicrobial effect against E. coli than CNPs .

A different method of nanocomposite formulation is to add the CNPs into the filler.

Such a filler was used to create a poly (methyl methacrylate) (PMMA) latex nanocomposite with bentonite-supported copper nanoparticles, which exhibited antimicrobial activity against S. aureus.

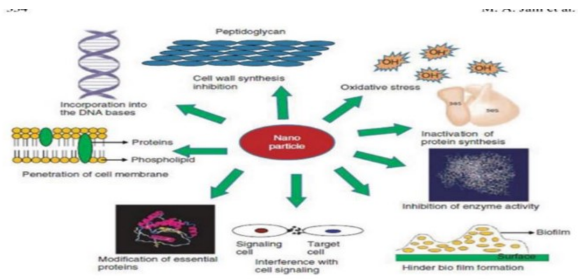

Figure 6

Methods of appling Nanoparticles as antibacterial to modify fabric

Nanoparticles can be applied by two methods to modify fabric as antibacterial.

Generally, first method involves direct deposition of metal NPs on the textile surface by some electrostatic force. In these methods colloidal metal nanoparticles are prepared using some reducing agent to reduce metallic salt to metal nanoparticles. Then polymeric textiles are directly immersed in colloidal solution containing metal NPs and are deposited on fibres. Sometimes surface modification of textile is done to enhance surface energy, to make surface rough so that adhesion/affinity between fibre surface and metal nanoparticles can be enhanced to a greater level.

In second method, metal ions are adsorbed at the surface, then, these ions are converted to metal NPs by UV radiation, heat treatment . or by some chemical reduction method.

Silver Nanoparticles

Silver ions and nanoparticles are most frequently used antibacterial agents that are integrated into fibers and onto fiber surface and have been reported for their most effective antibacterial activity against bacteria, viruses, and eukaryotic cells .

Silver has capability to attack the cell membrane and penetrate through it, causing malfunctioning of bacterial cell respiratory system, thus, responsible for the cells death .

studied the antibacterial activity of silver nanoparticles deposited on cationized cotton. Cationic agent (3-chloro-2-hydroxy propyl trimethyl ammonium chloride) in presence of alkali (NaOH) was used to make ordinary surface of cotton fibers cationic and increased affinity of cotton fibers for AgNPs that showed outstanding antibacterial activity. prepared bicomponent fibers using polypropylene (PP) and AgNPs by melt spinning method. AgNPs were in core and PP was spun as sheath of bicomponent fiber.

Surface modification of textile substrates with AgNPs and antibacterial activity was explored by using sodium hydroxide at different concentrations. Alkali treated cotton fabric was immersed in silver nitrate solution ($AgNO_3$) and then chemical reduction caused in situ AgNPs on fabric surface. Higher the concentration of NaOH more was silver content at surface. Homogeneously distributed NPs at treated fabric surface exhibited excellent antibacterial activity against Escherichia coli and Staphylococcus aureus. That procedure gave durable, superficial, cost effective method for higher silver content on textile surface .

In most recent studies electrospinning is fascinating technique for nanofiber fabrication. Researchers are developing electrospun nanofibers for different biomedical, filtration applications. Solution of cellulose acetate (CA) was direct electrospun containing $AgNO_3$ in small amount. Nanofibers containing Ag^+ ions. AgNPs were synthesized by direct UV irradiation of ultrafine CA fibers and stabilized by carbonyl oxygen in CA, having strong antibacterial activity because of silver NPs and unreduced ions of silver . In same way fibers chitosan/gelatin nanofibers containing AgNPs were fabricated, only difference was that, instead of γ or UV irradiation and heat treatment, AgNPs were synthesized by reducing agent like chitosan that also act as stabilizer for silver NPs . Nano AgZ (Silver-loaded zirconium phosphate nanoparticles) were added to PCL Poly(ε-caprolactone) and biocompatible fibers were electrospun for medical applications with enhanced bacteriostatic activities.

Carbon nanotubes Ag-coated CNTs were prepared by ultrasonic irradiation of dimethyl formamide (DMF) solution containing multi-walled carbon nanotubes, silver acetate

Copper nanoparticles (CNPs):

Up to this day, copper is used to hinder bacterial growth in many processes, such as water purification, and was proven to be effective against a wide variety of pathogens, Ligand is a molecule that produces a signal by binding to a site of a target protein to form a complex for a biological purpose. Copper ions can displace crucial metals from their native binding sites or interfere with biological functions via ligand interactions. Redox cycling reactions between Cu^{2+} and Cu^+ can trigger Fenton-like reactions, producing highly reactive hydroxyl radicals that attack the microbes' biomolecules . This results in a similar antimicrobial action as that described earlier.

Copper oxide nanoparticles (CuO-NPs) play an important role in many biological activities, such as antibacterial and antifungal activity, antioxidant properties, drug delivery, and cytotoxic efficacy against tumor and cancer cells, due to the highly interactive characteristics displayed. CuO-NPs have been manufactured through different biological entities, such as bacterial, fungal, actinomycetes, algae and plants. The utilization of fungal species as decreasing, covering and stabilizing agents to fabricate NPs is most interesting because of the presence of many secreted metabolites, high metal accumulation and scalability.

CuO-NPs are considered in applications such as antimicrobial activity against different pathogenic microbes, antioxidant activity, anticancer activity, antifungal against phyto-pathogenic fungi. CuO-NPs can be produced in many ways, including through physical, chemical and biological processes.

Different methods have been proposed for the synthesis of CuO-NPs, such as the sol–gel method, microwave irradiations, thermal decomposition, electrochemical technique and alkoxide-supported method.

The main disadvantages of these methods are the use of harmful chemicals, as well as thehigh energy consumption and high impurities in synthesized NPs.

On the other hand, the synthesis of CuO-NPs with green methods using multicellular and unicellular organisms such as actinomycetes, fungi, bacteria, plant or algae is gaining ground for pharmaceutical applications because of the biosafety of biosynthesized CuO-NPs.

Cu NPs play an important role in the textile industry because of the high natural abundance, low cost, practical, straightforward and multiple ways of preparing them.

Although bulk Cu can be used in many applications of various fields, such as optics, electronics, etc., the usage of Cu NPs is restricted. This is because of Cu's inherent instability under atmospheric conditions that lead to oxidation. Several attempts have been performed to increase the stability of Cu NPs by altering their sensitivity to oxygen, water and other chemical entities.

These efforts have encouraged the exploration of alternative Cubased NPs with more complex structures, such as core/shell Cu NPs or systems based on copper oxides. Cu, as a metal, has interesting physical and chemical properties. Firstly, it possesses a 3D transition; this gives Cu a wide range of accessible oxidation states (Cu0, CuI, CuII and CuIII), which can promote and undergo a variety of reactions. Cu-based Nano catalysts have many applications in nanotechnology, which are, mainly, catalytic organic transformations, electrocatalysis and photocatalysis.

The preparation of nanomaterials that are inexpensive, selective, stable, robust and highly active is the main purpose in the development of catalytic NPs. A cost-effective way of producing advanced Cu-based nanomaterials for catalysis is by coupling Cu NPs (e.g., Cu, CuO or Cu2O) with agents such as iron oxides, SiO2, carbon-based materials or polymers. Finally, the high boiling point of Cu NPs makes them compatible with high-temperature and high-pressure chemical reactions, such as continuous flow reactions, microwave-assisted reactions, vapor phase reactions and various organic transformations. Subsequently, it is obvious that Cu NP and its alloys will continue to play an important role in the future because of its unique properties.

The biggest drawback of using CNPs in polymers is that they can cluster together, thus reducing their antibacterial properties. The solution to that is creating silica nanospheres that will contain the CNPs inside them.

This approach can be applied in antimicrobic textile development, where nanocomposites can be used as coatings .

CuO nanoparticles have also been used via biosynthesis for the purpose of creating antibacterial-active textiles as cotton fabric. Researchers took advantage of the active ingredients, as enzymes, and the protein secreted by fungi, as the Aspergillus terreus strain AF-1, to cap CuO-NPs/proteins, taking into consideration their cytotoxicity.

CuO-NPs were also fabricated by utilising metabolites of the Aspergillus niger strain (G3-1), where functional groups of metabolites serve to cap and reduce, and are agents to stabilise the CuO-NP formation for an insecticidal purpose against wheat grain insects Sitophilus granarius and Rhyzopertha dominica .

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Conflict of Interest

There is no conflict of interest in the publication of this article.

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References

1. Ibrahim, A.; Laquerre, J.-É.; Forcier, P.; Deregnaucourt, V.; Decaens, J.; Vermeersch, O. Antimicrobial Agents for Textiles: Types,Mechanisms and Analysis Standards. In Textiles for Functional Applications; Kumar, B., Ed.; IntechOpen: London, UK, 2021;ISBN 978-1-83968-629.

2. Kumar, M.N.V.R. A Review of Chitin and Chitosan Applications. React. Funct. Polym. 2000, 46, 1–27.

3. Gupta, D.; Haile, A. Multifunctional Properties of Cotton Fabric Treated with Chitosan and Carboxymethyl Chitosan. Carbohydr.Polym

4. Dube, P.; Meyer, S.; Marnewick, J.L. Antimicrobial and Antioxidant Activities of Different Solvent Extracts from Fermented and Green Honeybush (Cyclopia intermedia) Plant Material. S. Afr. J. Bot. 2017, 110, 184–193.

5. Alaribe, F.N.; Maepa, M.J.; Mkhumbeni, N.; Motaung, S.C. Possible Roles of Eucomis autumnalis in Bone and Cartilage Regeneration: A Review. Trop. J. Pharm. Res. 2018, 17, 741–749.

6. Neely, A.N.; Maley, M.P. Survival of Enterococci and Staphylococci on Hospital Fabrics and Plastic in: Survival of Enterococci and Staphylococci on Hospital Fabrics and Plastic. J. Clin. Microbiol. 2000, 38, 724–726.

7. Huang, T.; Chen, C.; Li, D.; Ek, M. Hydrophobic and Antibacterial Textile Fibres Prepared by Covalently Attaching Betulin to Cellulose. Cellulose 2019, 26, 665–677.

8. Dastjerdi, R.; Montazer, M. A Review on the Application of Inorganic Nano-Structured Materials in the Modification of Textiles:Focus on Anti-Microbial Properties. Colloid Surf. B 2010, 79, 5–18.

9. Taylor, J. Microorganisms and Biotechnology, 2nd ed.; Bath Advanced Science; Nelson Thornes: Cheltenham, UK, 2001; ISBN 978-0-17-448255-0.

10. Renaud, F.N.; Doré, J.; Freney, H.J.; Coronel, B.; Dusseau, J.Y. Evaluation of Antimicrobial Properties of a Textile Product with Antimicrobial Finish in a Hospital Environment. J. Ind. Text. 2006, 36, 89–94.

11. Abdollahi, A.; Mahmoudzadeh, S. Microbial Profile of Air Contamination in Hospital Wards. Iran. J. Pathol. 2012, 7, 177–182.

12. Koca, O.; Altoparlak, U.; Ayyildiz, A.; Kaynar, H. Persistence of Nosocomial Pathogens on Various Fabrics. Eurasian J. Emerg.Med. 2012, 44, 28–31.

13. Morais, D.S.; Guedes, R.M.; Lopes, M.A. Antimicrobial Approaches for Textiles: From Research to Market. Materials 2016, 9, 498.

14. Gargoubi, S.; Tolouei, R.; Chevallier, P.; Levesque, L.; Ladhari, N.; Boudokhane, C.; Mantovani, D. Enhancing the Functionality of Cotton Fabric by Physical and Chemical Pre-Treatments: A Comparative Study. Carbohydr. Polym. 2016, 147, 28–36

15. Patel, K.J.; Patel, B.H.; Naik, J.A.; Bhavsar, A.M. Eco Friendly Dyeing with Extracts of Tulsi Leaves. In Natural Dyes: Scopes and Challenges; M.S. University: Gujarat, India, 2006; Volume 45, pp. 185–195, ISBN 8172334451/9788172334451.

16. Holme, I. Antimicrobials Impact Durable Finishes. Int. Dyer 2002, 12, 9–11.

17. Tandel, M.G.; Patel, B.H. Antimicrobial Finishing for Textiles; An Overview. Asian Dyer 2005, 5–6, 31–36.

18. Diffen, Gram Negative Bacteria vs. Gram Positive Bacteria. Available online: http://www.diffen.com/difference/Gramnegative_Bacteria_vs_Gram-positive_Bacteria (accessed on 9 September 2022).

19. Muñoz-Bonilla, A.; María, L.; Fernández-García, M. Polymeric Materials with Antimicrobial Activity from Synthesis to Applications,Chapter 1; The Royal Society of Chemistry: Cambridge, UK, 2014.

20. Gettings, R.L.; Triplett, B.L. A New, Durable Antimicrobial Finish for Textiles. In Book of papers; Fibre2fashion: Ahmedabad,India, 1978.

21. Nortjie, E.; Basitere, M.; Moyo, D.; Nyamukamba, P. Extraction Methods, Quantitative and Qualitative Phytochemical Screening of Medicinal Plants for Antimicrobial Textiles: A Review. Plants 2022, 11, 2011.

22. Magill, S.S.; Edwards, J.R.; Bamberg, W.; Beldavs, Z.G.; Dumyati, G.; Kainer, M.A.; Lynfield, R.; Maloney, M.; McAllister-Hollod,L.; Nadle, J.; et al. Multistate Point-Prevalence Survey of Health Care–Associated Infections. N. Engl. J. Med. 2014, 370, 1198–1208.

23. Yayan, J.; Ghebremedhin, B.; Rasche, K. Antibiotic Resistance of Pseudomonas Aeruginosa in Pneumonia at a Single University Hospital Center in Germany over a 10-Year Period. PLoS ONE 2015, 10, e0139836.

24. Reza, A.; Sutton, J.M.; Rahman, K.M. Effectiveness of Efflux Pump Inhibitors as Biofilm Disruptors and Resistance Breakers in Gram-Negative (ESKAPEE) Bacteria. Antibiotics 2019, 8, 229.

25. Simoes, J.A.; Citron, D.M.; Aroutcheva, A.; Anderson, R.A.; Chany, C.J.; Waller, D.P.; Faro, S.; Zaneveld, L.J.D. Two Novel Vaginal Microbicides (Polystyrene Sulfonate and Cellulose Sulfate) Inhibit Gardnerella vaginalis and Anaerobes Commonly Associated with Bacterial Vaginosis. Antimicrob. Agents Chemother. 2002, 46, 2692–2695.

26. Candan, A. The Waste Problem of Antimicrobial Finishing. In Waste in Textile and Leather Sectors; IntechOpen: London, UK, 2020.

27. Gao, Y.; Cranston, R. Recent Advances in Antimicrobial Treatments of Textiles. Text. Res. J. 2008, 78, 60–72.

28. McDonnell, G.; Russell, A.D. Antiseptics and Disinfectants: Activity, Action, and Resistance. Clin. Microbiol. Rev. 1999, 12, 147–179.

29. Windler, L.; Height, M.; Nowack, B. Comparative Evaluation of Antimicrobials for Textile Applications. Environ. Int. 2013, 53,62–73.

30. Kegley, S.E.; Hill, B.R.; Orme, S.; Choi, A.H. Pan Pesticide Database, Pesticide Action Network, North America; Pesticide Action Network: Oakland, CA, USA; San Francisco, CA, USA, 2010.

31. Simoncic, B.; Tomsic, B. Structures of Novel Antimicrobial Agents for Textiles—A Review. Text. Res. J. 2010, 80, 1721–1737.

32. Jain, A.; Duvvuri, L.S.; Farah, S.; Beyth, N.; Domb, A.J.; Khan, W. Antimicrobial Polymers. Adv. Healthcare Mater. 2014, 3,1969–1985.

33. Kamel, M.Y.; Hassabo, A.G. Anti-Microbial Finishing for Natural Textile Fabrics. J. Text. Color. Polym. Sci. 2021, 18, 83–95.

34. El-Ola, S.M.A. Recent Developments in Finishing of Synthetic Fibres for Medical Applications. Des Monomers Polym. 2008, 11,483–533.