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Advancements in Bioactive Textiles: A Review of Antimicrobial Fabric Finishes and Commercial Products

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Abstract

The demand for bioactive or antimicrobial fabrics has increased as people's knowledge of health and hygiene issues has grown. A bioactive finish on the fabric serves two purposes. It shields the wearer from germs for reasons related to hygiene, aesthetics, or health, and it shields the textile from biodeterioration brought on by fungi, mold, and mildew. Research on new quality standards, such as preserving the product's inherent usefulness through an environmentally friendly production process, is ongoing on a global scale. The mechanism of action of antimicrobial textile finishes against microbes is reviewed in this paper along with recent advancements in this field. Additionally covered are the bioactive textiles and fibers that are sold commercially.

Keywords: antibacterial; preparing; ecofriendly; plasma; supercritical; Microcapsules , nanotechnology; plant extracts

Introduction

Many antimicrobial textile materials are developed using a variety of active agents that include synthetic antimicrobial agents such as triclosan, metals and their salts, phenols, quaternary ammonium compounds, and organic minerals. Although synthetic antimicrobial agents effectively inhibit the growth of microbes, most of them are toxic, can cause adverse effects on human health, and have environmental problems. Current studies demonstrate that many environmentally friendly antimicrobial substances are effective against both Gram-positive and Gram-negative bacteria depending on the use of natural antimicrobial compounds derived from plants such as neem, [1, 2] tea tree, [3-5] azuki bean, aloe vera, [6-9] tulsi leaf (Ocimum saintum), [10, 11] clove oil, [12] and pomegranate peel. [13-15]

Turmeric, [16-18] eucalyptus oil, [12, 19, 20] onion peel and pulp extracts [21-24] in textile processing. and this antimicrobial treatment can be accomplished by first turning the textile's inert surface into a reactive one before applying an antibacterial chemical. A modification is a restricted alteration made to a material's properties, whereas a surface modification is any physical or chemical alteration made to the material's surface that can be caused by chemical, physicochemical, or biological processes. One of the physicochemical techniques that can be used to convert a nearly inert surface into a reactive one in surface engineering is plasma surface modification of a textile. [25]

A tiny portion of the textile fiber is represented by its surface, that is just 1-2% of the total mass of fiber Its quality, however, determines whether or not the material can be used to create a desirable textile product, and for some applications, the opposite is also true. For this reason, its position in textile processing is crucial. For hydrophobic applications, for example, the surface should be rendered water-repellent. The contemporary textile market has shown a significant deal of interest in functional textiles, one of which is antimicrobial, making surface modification an essential preprocess phenomenon. Surface modification ofis, due to its

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many advantages, one of the most promising options for producing practical textiles. [26]

Likewise, nanotechnology, microcapsules, and supercritical methods. These methods are significant because they impart certain qualities to the treated surface that traditional methods are unable to provide. It modifies the surface of the textile fibers in a certain way without changing their bulk characteristics. More significantly, using this technique results in an operating condition that is non-polluting and meets environmental pollution control regulations. [14, 27]

Antimicrobial preparation with traditional methods

Microorganisms can grow on textile structures because of their huge surface area and capacity to hold moisture. This can have a variety of negative impacts on the user as well as the textile itself. Intense research has been encouraged in recent years to reduce the growth of microorganisms on textiles due to public health awareness of the harmful impact on personal hygiene as well as associated health hazards. [28]

Thus, various methods have been investigated to give textiles an antimicrobial property; these methods are primarily classified into two categories: adding antimicrobial compounds to textile polymeric fibers or grafting them onto the polymer surface. Many kinds of antibacterial agents have been employed, including triclosan, metal salts, polybiguanides, quaternary ammonium compounds, and even naturally occurring polymers. In addition to being effective against microbes, any antimicrobial treatment applied to a textile needs to be safe for both the environment and consumers. [2, 3, 9, 29-45]

The primary goal of this review is to give a general overview of antimicrobial agents and treatments that can be used in chemical or physical ways to create antimicrobial textiles. These treatments and agents may be isolated agents, textile fibers or fabrics, or they may already be commercially available. Certain methods rely on the application of certain antimicrobial chemicals, which in the case of synthetic fibers might be mixed into the polymeric matrix. [28, 46]

Another option is to apply antimicrobial compounds to the material surface during the finishing stage, which may be applied to both natural and synthetic fibers as well as any type of textile fabric. Based on the strategy When utilized, antimicrobial textiles can function by either diffusion or contact. The agent only acts when the microorganism comes into contact with the textile surface because, in the event of contact, it is applied to the fiber and does not disperse. [47]

In the event of diffusion, the agent is present in the polymeric matrix or on the fiber surface, and it moves from the textile to the external medium in order to fight the microbes. Based on their chemical and structural makeup, affinity for certain target locations within microbial cells, and other factors, the majority of antimicrobial agents used in commercial textiles are biocides that work in various ways. [29]

These various mechanisms of action could include: Inhibition of cell membrane function, which is an essential component for the life and survival of bacterial species; Damage or inhibition of cell wall synthesis crucial barrier that controls the flow of substances both inside and outside of cells, which could cause the leaking of solutes essential to the survival of the cells inhibition of nucleic acid synthesis (DNA and RNA) because some antimicrobial agents bind to components involved in the process; inhibition of protein synthesis, which is the foundation of cell enzymes and structures and ultimately results in the death of the organism or the inhibition of its growth and multiplication. The multiplication and survival of microorganisms are compromised by this inhibition, which tampers with regular cellular functions. Inhibition of other metabolic processes, such as the disruption of the folic acid pathway, which is necessary for bacteria to create precursors crucial for DNA synthesis. A sample of a substance that can fend off germs is: Metallic salts and chitosan/metals TiO_2 and ZnO/Triclosan are two examples. [47, 48]

Processing against microbes using modern technologies and Environmentally friendly materials

Plasma

An ionized gas state of matter known as a plasma is made up of free electrons, ions, and a significant amount of visible, ultraviolet, and infrared radiation. Given that its characteristics differ from those of solid states of matter, condensed liquids, and unionized gases, it is referred to be the fourth state of matter. Nuclear energy (fission, fusion) and electrical energy (electric discharges) are two ways to create the plasma state. [44, 49-54]

Mechanical energy (shock waves) and thermal energy (strong redox reactions, such as flames)

radiant energy, which includes particle and electromagnetic radiation. [13]

Types of plasma

Plasma systems have a wide variety of potential substance therapies. Industrial plasma technology uses two main forms of plasma

1- the first "thermal plasma" generated by direct and alternate (dc-ac) current or by microwave source at high-pressure (>10kPa). The devices produce plasmas with 1-2 eV electron and ion temperatures and very low gas ionization. Thermal plasma may be used to dissolve or produce anti-corrosion, thermal barriers, anti-wear coatings, solid, liquid, and gaseous radioactive halogenated and dangerous compounds.

2- The second type of plasma, called cold or non-balance plasma, has a higher electron temperature than ion. It has been traditionally considered that low-pressure plasmas, working between 0.1 pa and 100 pa.

Non-thermal plasmas or cold plasmas are commonly used. Textile plasma operations are either under vacuum pressure or under pressure from the atmosphere. Plasmas are the most inimitably effective surface treatment tools. [55]

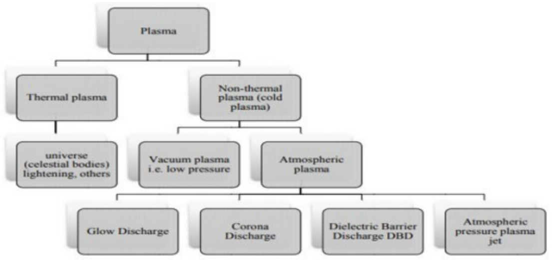

Figure 1: types of plasma. [55]

A Study on Chitosan Modification of Polyester Fabrics by Atmospheric Pressure Plasma and Its Antibacterial Effects

Because of its intrinsic nontoxic biopolymer properties and antibacterial properties, chitosan is widely used in many different fields. This study assessed the characteristics of polyester fabrics that have been grafted with chitosan oligomers or polymers and activated by atmospheric pressure plasmas. When materials were grafted with chitosan oligomers and their surfaces activated by atmospheric pressure plasma for 60 to 120 seconds, the antibacterial effect was most noticeable. Additionally, the altered textiles showed good biocompatibility. This technique can be used to create antibacterial polymer fibers and is widely applicable. [56]

Antimicrobial nano-silver non-woven polyethylene terephthalate fabric via an atmospheric pressure plasma deposition process

Three steps have been taken to prepare an antimicrobial nano-silver non-woven polyethylene terephthalate (PET) fabric. Using an atmospheric pressure plasma system, an organosilicon thin film layer was first applied to the fabrics as a pretreatment step. Next, silver nanoparticles (AgNPs) were incorporated into the fabrics through a dipping-dry process. Lastly, a second organosilicon layer, measuring 10–50 nm, was applied to the nanoparticles, serving as a barrier layer. The shape and chemical composition of the nano-silver textiles have been studied using a variety of surface characterization techniques, including as SEM and XPS. These methods have led to the observation of an even immobilization of AgNPs in the PET matrix. P. aeruginosa, S. aureus, and C. albicans have also been used to test the treated fabrics' antimicrobial efficacy. It demonstrates that the barrier layer's thickness has a significant impact on the materials' ability to reduce bacteria. In a washing process, the AgNPs' stability and longevity on the fabrics have also been studied. By doing this, it is established that the barrier layer can successfully stop AgNPs from escaping and that a key factor in regulating the release of silver ions is the barrier layer's thickness. [57]

Atmospheric pressure plasma deposition of antimicrobial coatings on non-woven textiles

Based on the atmospheric pressure plasma process, a straightforward procedure for creating non-woven fabric with nanoparticle integration and strong antibacterial efficacy has been shown. In this work, the source of plasma deposition was a direct current plasma jet stabilized by fast nitrogen flow. As antibacterial agents, three distinct kinds of nanoparticles—copper, zinc oxide, and silver—were used. A positive chemical shift for Ag 3d5/2 (at 368.1 eV) has been detected in X-ray photoelectron spectroscopy (XPS) experiments, which implies that silver nanoparticles (AgNPs) are partially oxidized during the deposition process. Investigations and analyses were done on the surface chemistry and antibacterial activity of the samples against Escherichia coli and Staphylococcus aureus. It is demonstrated that samples containing Ag and Cu nanoparticles and with a 10 nm barrier layer are defined by Staphylococcus aureus is reduced by 86% in samples containing ZnO nanoparticles, compared to nearly 97% in samples without them. [58]

Effect of plasma superficial treatments on antibacterial functionalization and coloration of cellulosic fabrics

Different cellulosic substrates, such as cotton, linen, viscose, and lyocell, showed remarkably improved antibacterial activity and durability after pre-surface modification with N2-plasma to create new active and binding sites, -NH2 groups, onto the modified fabric surfaces. This was followed by the loading of biosynthesized silver nanoparticles (Ag NPs), both alone and in combination with specific antibiotics, using the exhaustion method. The kind of substrate, degree of alteration and subsequent loading of antibacterial agent, synergistic impact, antibacterial activity, and type of pathogenic bacteria influenced the imparted antibacterial activity against both G+ve (S. aureus) and G−ve (E. coli) pathogens. Even after fifteen washings, a strong antibacterial activity was still present. Furthermore, adding Ag NPs to the acid dyeing bath and pigment printing paste for. It was effective to combine the coloring and functionalization of O2-plasma and N2-plasma pre-modified substrates, respectively.Furthermore, the surface morphology of the chosen substrates was altered, and the loaded Ag element was visible on the post-treated substrates according to both SEM pictures and EDS spectra. [59]

Investigation of antibacterial activity on cotton fabrics with cold plasma in the presence of a magnetic field

Microorganisms have been found to be able to grow on a textile substrate. Because of their hydrophilic structure, which allows them to retain nutrients, water, and oxygen, natural fibers like cotton are more prone to bacterial development than synthetic ones. Numerous antimicrobial coatings have been created recently and can be applied to textiles. Prior attempts relied on the insolubilization of inorganic substances, such as copper and various salts of organometallic compounds. The ability of copper to sterilize objects stops bacteria, fungus, and germs from growing. In dry systems, low temperature plasma (LTP) is a helpful method for surface-modifying polymers and textile textiles. In this study, we have created antibacterial characteristics on cotton fabrics using a DC magnetron sputtering technique. Samples were made using a copper cathode and anode got positioned on the anode. Attacking electrons, radicals, and active ions dispersed the cathode particles. Cotton samples were coated with copper particles, and by incorporating copper particles onto fabric surfaces, an antibacterial was created. The materials' surface concentration of copper was linked to their antibacterial qualities. Following plasma treatment, textile technology testing and surface analysis techniques were used to evaluate the materials' chemical and physical characteristics. The Halo approach was also utilized to measure the antibacterial efficiency. According to the experimental results, some textile items may benefit from the modifications in characteristics brought about by LTP. [60]

Supercritical

Supercritical in the sense that it exceeds the critical temperature and critical pressure, where the material is in a state between the gaseous and liquid state, where it has the ability to penetrate some solid materials just like gas and dissolve some materials such as liquid, for example carbon dioxide is supercritical in a state Between the gaseous and liquid state, as it has a density like a liquid and a viscosity like a gas, and therefore it is used as a solvent, and it is also distinguished by its availability and non-toxicity. [61]

Single-step disperse dyeing and antimicrobial functionalization of polyester fabric with chitosan and derivative in supercritical carbon dioxide

In this work, a revolutionary green strategy was used to create antimicrobial polyester fabric in a single step utilizing resource-efficient supercritical CO2 (scCO2) dyeing, which uses sustainable biopolymers (chitosan/derivative) as eco-friendly antimicrobial agents. A little bit of dye (0.4 percent owf) was used to color polyester cloth while chitosan or its derivative (3 percent owf) was present in scCO2 at 120 degrees Celsius and 25 MPa for an hour. Measurements using Fourier Transform Infrared (FTIR), Zeta Potential (δ), Scanning Electron Microscopy (SEM), and Water Contact Angle (WCA) were used to verify the efficacy of the chitosan/derivative impregnation process. The treated materials yielded outstanding color strength and fastness qualities, and after one hour, they eliminated 75−93% of Escherichia coli (ATCC 25922) bacteria. This implies that the colorant and its derivative, chitosan, had no negative impact on one another, demonstrating compatibility. With this innovative strategy, the production costs and environmental damage linked to traditional textile finishing methods would be decreased. [62]

Impregnation of corona modified polypropylene non-woven material with thymol in supercritical carbon dioxide for antimicrobial application

In order to create environmentally friendly antimicrobial textile material, this study explores the feasibility of impregnating polypropylene (PP) and corona modified PP nonwoven material with thymolin supercritical solvent. The operating fluid was carbon dioxide. FESEM examination verified the presence of thymol on the fiber surface during impregnation and the morphological changes on the PP fiber surface caused by corona treatment at atmospheric pressure. Analyses using FTIR were used to evaluate chemical changes. The modified polypropylene non-woven material's antimicrobial activity was evaluated against the fungus Candida albicans, the Gram-positive bacterium Staphylococcus aureus, and the Gram-negative bacterium Escherichia coli. While thymol-impregnated PP non-woven material and corona activated PP impregnated with thymol both offered maximal microbial reduction, the corona pre-treated material wetted considerably faster, which could be advantageous in wound recovery. [63]

Facile Bifunctional Dyeing of Polyester under Supercritical Carbon Dioxide Medium with New Antibacterial Hydrazono Propanenitrile Dyes

In this work, supercritical carbon dioxide was used as a dyeing medium to color polyester garments using new hydrazonopropanenitrile dyes that may have antimicrobial properties. To get consistent dye uptakes in the cloth that could be seen and measured using spectrophotometry, the experimental setup was improved. Raman micro-spectroscopy clearly showed that the dye had penetrated all of the fabric's layers. By using K/S measures, the fabric's color strength was assessed and found to be greater than that of traditional dyeing. Excellent findings were obtained from the evaluation of the dyed fabric's fastness capabilities. The AATCC procedure was followed when conducting the antibacterial test, and the outcomes were noted.

In contrast to traditional water dyeing, no effluent was generated throughout the dying process. The Compared to the traditional method, dyeing was significantly more efficient. There are unquestionably some benefits to scCO2 dyeing. The ideal dye concentration varies from 2–6% owf, while the ideal dyeing temperature and pressure are 120 °C and 15 MPa, respectively. Our results indicate that the color yield, water-wash, rubbing, and light fastness were all outstanding. Excellent antibacterial efficacy against both G +ve and G -ve bacteria was also demonstrated by all dyed samples. Our investigation into these dyes' dyeing efficacy on other textiles, like nylon and polypropylene, was spurred by the outcomes we saw, and the findings will be documented in our next work. [64]

Antifungal Textiles Formed Using Silver Deposition in Supercritical Carbon Dioxide

Two natural cotton fiber architectures plated in silver and made with a supercritical carbon dioxide (scCO2) solvent were tested for their antifungal qualities. The scCO2 technique can be utilized to create cotton fiber textiles with consistent silver nanoparticle coatings, as validated by scanning electron microscopy. The efficacy of these fabrics to impede fungal growth was evaluated using a modified version of the Kirby-Bauer disk diffusion test. Ag(hepta) and Ag(cod)(hfac)-modified cotton fabric samples showed detectable zones of inhibition. The uncoated cloth, however, lacked a zone of restriction. Wound treatments and hospital uniforms are two potential uses for antifungal fabrics made using scCO2 processing. [65]

Microcapsules

Active compounds can be effectively contained at the micro- or nanometric scale within a matrix or polymeric membrane by a process known as microencapsulation. This keeps the compounds safe from the outside world, preserves their reactivity, and permits their release when the desired circumstances are met. A micro- or nano capsule is a small part of an active material encapsulated in an encapsulating agent whose dimensions are in the micro- or nanometer range, separating the material from the surrounding medium. [25, 66-72]

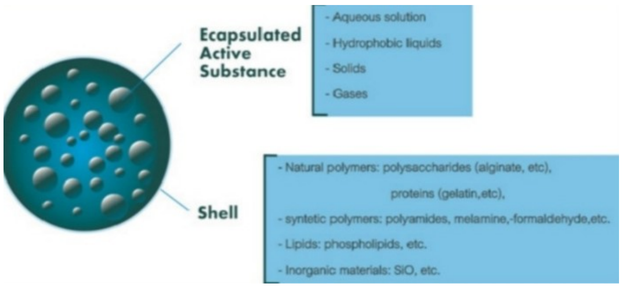

Figure 2: Structure of micro capsule. [73]

Either a liquid or solid form of the active ingredient is possible. It also describes the interior stages, fillers, encapsulations, and core components. The active components are surrounded by what is sometimes referred to as the wall, shell, exterior phase, membrane, or matrix—a polymer coating. It could be a synthetic, semi-synthetic, or natural polymer. Friction, pressure, temperature or pH changes, diffusion through the polymer wall, dissolving of the polymer wall coating, and biodegradation are some of the processes that can release the core substance. Many encapsulation technologies are available today, depending on the active ingredient and the microcapsules' intended use. Three different technologies can be used to encapsulate active ingredients in capsules that are both micro- and nanosized: Chemistry / Procedures Processes that are both physical and chemical or mechanical. [73]

Antimicrobial activity of cotton and silk fabrics with herbal extract by microcapsulation

To investigate the antibacterial properties of neem, tulsi, and turmeric-encapsulated microcapsules and their use on cellulosic fabric. Methods: The simple diffusion method, a yeast-based natural encapsulating approach, was used to create the microcapsules from the herb mixture. They were then applied to cotton and silk fabrics using the pad-dry-cure process. The UF Silpure FBR-5(PA)B binder was used to glue the microcapsules on cotton and silk fabrics at a temperature of 120°C. Staphylococcus aureus, Escherichia coli, and pseudomonas were the three species of bacteria used to evaluate the antibacterial activity of the final fabric. Findings: The antibacterial activity of the combination of herbs was demonstrated to be highly active by the results of tests using the parallel streak method and the disc diffusion method among the three species of bacteria that were chosen, and the produced microcapsule had excellent antibacterial efficacy against Pseudomonas. Conclusions: The cloth treated with herbal microcapsules may find use in the medical field. The photos taken with a scanning electron microscope guarantee that the microcapsules are securely fixed in the yarn structure of the silk and cotton plain weave fabric. [74]

Microparticles loaded with propolis to make antibacterial cotton

The purpose of this study was to elucidate the antibacterial properties of cotton fabrics coated with microcapsules loaded with propolis for the first time. To create the microcapsules, gum arabic and Type-B gelatin were used in accordance with a complex coacervation method, and glutaraldehyde was applied as a crosslinking agent. The performance of the microcapsule-padded cotton fabrics was assessed using microcapsules with varying ratios of wall materials, padding times, and concentrations of propolis and crosslinker. Cotton fabrics embedded with microcapsules whose core material is propolis have antibacterial properties against both gram positive and gram-negative bacteria. After washing the microcapsule-treated cotton fabrics five and ten times, it was observed that their antibacterial effect extiles both before and after washing. Cotton textiles with microcapsule implanted in them were assessed using Fourier Transform Infrared Spectroscopy (FTIR) and Thermogravimetric Analysis (TGA). [75]

Aroma-loaded microcapsules with antibacterial activity for eco-friendly textile application: synthesis, characterization, release, and green grafting

Cotton fabrics were given fragrant and antibacterial qualities after being microencapsulated with eco-friendly ingredients. By employing tannic acid as a hardening agent and chitosan or gum Arabic as the shell materials, limonene and vanillin microcapsules were created by a sophisticated coacervation process. Two emulsifiers, Span 85 and polyglycerol polyricinoleate (PGPR), were investigated for their effects on the encapsulation efficiency (EE%), size and shape of microcapsules, and cumulative release profiles. The microcapsules that were generated had a mean diameter that varied from 10.4 to 39.0 µm, and their EE% was found to be between 90.4% and 100%. Whichever core material was used—limonene or vanillin—PGPR produced polynuclear structures while Span 85 produced mononuclear morphology. The microcapsules produced exhibited a sustained release pattern. Specifically, following a week at 37 ± 1°C, the total cumulative release of the active agents was 75%, 52 and 19.4% for the polynuclear limonene microcapsules, mononuclear limonene microcapsules, and polynuclear vanillin microcapsules, in that order. SEM and FTIR spectroscopy were used to confirm the grafting of the created microcapsules onto cotton fabrics using an esterification reaction employing citric acid as a nontoxic cross-linker, followed by thermofixation and curing. Both the microcapsules alone and the fabrics impregnated with them demonstrated a persistent antibacterial action in standard antibacterial testing. [76]

Tea tree oil/ethyl cellulose microcapsule loaded antimicrobial textiles

The purpose of this experimental investigation was to apply tea tree oil/ethyl cellulose (TTO/EC) microcapsules to cotton fabrics in order to produce disposable antimicrobial fabrics. The TTO/EC microcapsules were manufactured and evaluated using Fourier transform infrared-attenuated total reflectance (FTIR-ATR) studies and scanning electron microscopy (SEM) for this purpose. Following their application to 100% cotton fabric samples using the padding method, the described microcapsules were examined using SEM and FTIR-ATR studies. Additionally, against the microorganisms Escherichia coli and Staphylococcus aureus, the antibacterial properties of TTO, TTO/EC microcapsules, and fabric samples were evaluated. The outcomes demonstrated that the preparation and application of the microcapsules to the fabric samples were successful. Furthermore, the textile surfaces' intended antibacterial activities were accomplished within tolerable limits. [30]

Study on the grafting of chitosan–gelatin microcapsules onto cotton fabrics and its antibacterial effect

In this work, the complicated coacervation process was used to create chitosan–gelatin microcapsules impregnated with patchouli oil. Scanning electron microscopy (SEM) was used to analyze the microcapsules' surface and morphology, revealing that they had a regular, spherical form between 1 and 20 µm. The microcapsules in the thermal stability analysis were stable below 190 °C, suggesting that the fabric finish can be carried out at 160°C. The microcapsules' loading capacity (LC) and encapsulation efficiency (EE) were determined to be 30.31 and 50.69%, respectively. Next, utilizing 2D resin (dimethyloldihydroxyethylene urea, or DMDHEU) as the crosslinking agent, the microcapsules were grafted onto cotton textiles.

SEM revealed that the microcapsules were injected into the spaces between the textiles in addition to being grafted on their surface.the fibers. Furthermore, Fourier transform infrared spectroscopy (FTIR) was used to detect the creation of ether bonds between the hydroxyl groups of the microcapsules and/or cotton hydroxyl groups and 2D resin. Lastly, even after 25 washings, the materials' antibacterial rates against Staphylococcus aureus and Escherichia coli were roughly 65%, indicating that they could find use in a variety of industries, including the production of bacteriostatic sheets, antibacterial masks, and medical apparel. [77]

Development of a cotton smart textile with medical properties using lime oil microcapsules

The goal of this study was to use the microencapsulation technology to create a cotton fabric that was both antibacterial and antioxidant-active by encapsulating lime oil (LO). Chitosan and gum Arabic wall components were used in the complicated coacervation process to create LO microcapsules. FTIR and UV-Visible spectrometry confirmed that LO had been successfully encapsulated. According to the optical and SEM photos, the produced LO microcapsules varied in size and had an irregular form, measuring between 15 and 160 µm. The microcapsules were found to have a loading of 2943 ± 128 µL/g. a performance of 82 ± 4%. According to the Folin-Ciocalteu assay, the LO microcapsules had an antioxidant activity of 1336 ± 17 µg PGE/g.

According to the brine shrimp lethality assay, microencapsulation reduced the cytotoxicity of LO. Saccinic The binder was made of acid.to incorporate the LO microcapsules on to the cotton fabric. The SEM images confirmed the steady attachment of LO microcapsules to the cotton fibres. The cotton fabric containing LO microcapsules displayed significant antibacterial activity against four bacterial species prior to and after subjecting the fabric to wash conditions. [78]

Preparation of Antibacterial Cotton Fabric Containing Patchouli Oil Microcapsules by Chemical Crosslinking Method

This study looked into a novel type of cotton fabric that is antimicrobial and contains microcapsules of patchouli oil. Using a sophisticated coacervation process, the patchouli oil microcapsules were created, and they were then grafted onto cotton fabric using a chemical crosslinking technique. 1,2,3,4-butanetetra-carboxylic acid (BTCA) was used as the crosslinking agent. The scanning electron microscope (SEM) was used to characterize the surface and morphology of fabrics. Using Fourier transform infrared spectroscopy (FTIR), the hydroxyl groups of cotton and patchouli oil microcapsules and BTCA were studied for the formation of ester linkages. By using the releasing test and the laundering test, the antibacterial fabrics' releasing properties and antimicrobial durability were also examined. The findings demonstrated that the crosslinking agent BTCA played a role in the patchouli oil microcapsules' grafting onto cotton fabric. and the treated fabric represented persistent effect, slow releasing performance and washable antibacterial properties. After 30 days, the patchouli oil in the microcapsules was still remained on the fabric and the releasing amount was near 50%. About 72% antibacterial rate of the fabric for staphylococcus aureus and candida albicans could be obtained after washed 30 times, furthermore, no formaldehyde releasing can be found. It is suggested that chemical crosslinking method would provide a potential application in functional finishing by microcapsules for cotton fabric. [79]

Preparation of antibacterial citronella oil microcapsules and their application in cotton fabrics

utilizing gelatin and arabic gum as the wall materials, the complex coacervation process was utilized to successfully create the citronella oil microcapsules. The microcapsules were then applied to modify cotton fabrics utilizing 2D resin as the cross-linking agent. Scanning electrical microscopy was used to characterize the cotton textiles and the microcapsules. The outcomes demonstrated that the citronella oil microcapsules were successfully grafted onto fabrics and had an average diameter of 10 µm. Additionally, the results of the release and antibacterial tests demonstrated the modified cotton materials' outstanding antibacterial efficacy and slow release performance. [80]

nanotechnology

The word (nano): The origin of the word “nano” is derived from the Greek word (nanos), which is a Greek word that means dwarf, and it means everything that is small The nanoscale includes dimensions from one nanometer to 100 nanometers in length. Nanoscience is the study of the basic principles of molecules and compounds less than 100 nanometers in size. Nanoparticles are an atomic or molecular aggregation of a few to a million atoms (or molecules) bound together in a roughly spherical shape with a radius of less than 100 nanometers. A particle with a radius of one nanometer contains 25 atoms. [81]

Preparation and Characterization of Zinc Oxide Nanoparticles and a Study of the Anti-microbial Property of Cotton Fabric Treated with the Particles

Over the past ten years, nanotechnology—an emerging multidisciplinary technology—has experienced rapid growth in a variety of fields. The physical characteristics of conventional textiles, such as their antibacterial, water-repellent, soil-resistant, antistatic, anti-infrared, and flame-retardant qualities, dyeability, color fastness, and strength, can be improved by nanostructures. In the current work, investigations have been conducted to optimize the characteristics of zinc oxide nanoparticles for certain uses. Through the use of soluble starch as a stabilizing agent, zinc nitrate, and sodium hydroxide as precursors, zinc oxide nanoparticles were produced via a wet chemical technique. The produced nanoparticles were applied to cotton fabric (honeycomb weave), and the coated fabric's antibacterial properties were ascertained. Methods like physical and scanning electron microscopy (SEM). To ascertain the phase and shape of the finished nanoparticle-coated cloth, chemical analysis was utilized. According to the findings, coated cloth containing 2% zinc oxide nanoparticles has a high level of antibacterial activity—up to 99.9%. The average size of the nanoparticles created in this work is 50 nm, and the treated fabric differs significantly from the untreated fabric in terms of both its chemical and physical properties. [82]

Nanostructured copper oxide-cotton fibers: synthesis, characterization, and applications

By using ultrasonic irradiation, copper oxide nanoparticles were created and then applied to the cotton fiber surface. X-ray diffraction and scanning electron microscopy/energy dispersive X-ray analysis were used to analyze the structure and morphology of the coated and uncoated cottons. By using these techniques, it was discovered that CuO nanoparticles are crystalline, belong to the monoclinic phase, and are physically adsorbed onto the surface of cotton fiber. The treated cotton fibers have distinct physical and chemical properties from the untreated cotton fibers, with an average crystallite size of 10 nm. When tested against Gram-negative and Gram-positive cultures of Escherichia coli and Staphylococcus aureus, the CuOcotton fiber nanocomposites shown strong antibacterial activity; in contrast, the corresponding CuS-coated cotton material created by CuO-coated cotton fibers with H2S did not react in any way. [83]

Surface modification of textiles by green nanotechnology against pathogenic microorganisms

Within the hospital setting, infections brought on by pathogenic and opportunistic microorganisms are a significant cause of death. As a result, it's critical to find strategies to reduce the quantity of illnesses contracted there. Fabrics can be a significant source of contamination because they are in continual contact with the patient. The creation of hospital fabrics that stop bacteria from adhering to and growing on their surface is an alternative. AgNPs, or silver nanoparticles, have the ability to fight microbes and can be used in this way. This work describes the green nanotechnology-based, quick, easy, and environmentally friendly synthesis of AgNPs and their use in hospital cotton fabrics to efficiently inhibit microbial growth at all tested doses without causing cytotoxicity in mammals. AgNPsexamined utilizing a transmission electron microscope (TEM), a UV-Vis spectrophotometer, and beta vulgaris extract biosynthesis.Zeta potential, energy-dispersive X-ray spectroscopy (EDS), and scanning electron microscopy (SEM). AgNPs shown efficacy against the yeast Candida albicans, the Gram-positive bacteria Staphylococcus aureus and Staphylococcus epidermidis, and the Gram-negative bacteria Escherichia coli. The fabrics showed good antimicrobial capabilities, which opens the door to their possible use as smart textiles in healthcare settings that have microbicidal activity. At the concentrations examined, no cytotoxic effects on HEK293 or HeLa cells have been documented. Because they prevent microbial development, these smart fabrics could therefore be utilized in medical settings for things like pillows and linens. As a result, they would aid in preventing infections in hospitals brought on by opportunistic bacteria that they contain. [84]

Adopting a green method for the synthesis of gold nanoparticles on cotton cloth for antimicrobial and environmental applications

In this study, a straightforward and environmentally friendly method for producing biogenic gold nanoparticles on cotton fabric (AuNPs-CC) was created. It was discovered that the Au ions were gradually converted to nanoparticles by the hydroxyl functional groups of the cellulose macromolecules, which are widely distributed in cotton. The kinetic process of AuNP production was sped up by using a concentration of citrus limon juice. Energy-dispersive spectroscopy (EDS), a field emission scanning electron microscope (FESEM), and other spectroscopic techniques were used to evaluate the samples. The ~22 nm size AuNPs adhered to the cotton cloth fibers were clearly visible in the FESEM pictures. The production of biogenic AuNP on the CC surface was validated by XPS and XRD. Using their respective strains, the bactericidal properties of the pristine-CC and AuNPs-CC were investigated. Furthermore, AuNPs-CC was employed as a catalyst for the breakdown of the contaminants ortho- and para-nitrophenol in their aqueous solutions. With high reaction rate constants, the p-NP and o-NP reductions were catalyzed by the AuNP-CC. Furthermore, pathogenic bacteria are susceptible to the antibacterial properties of Citrus Limon-assisted Synthesized AuNP-CC. [85]

Iron oxide nanoparticles synthesized in situ on polyester fabric using sono-Fenton catalytic, color, magnetic, and antibacterial characteristics

By utilizing ferric chloride, ferrous sulfate, and sodium hydroxide in the in situ production of magnetite and hematite nanoparticles, multifunctional polyester fabric with magnetic, antibacterial, and sono-Fenton catalytic properties was created. The procedure produced Fe_3O_4 and α-Fe_2O_3 nanoparticles at two distinct temperatures, 100 °C and 130 °C. Through the use of scanning electron microscopy (SEM), X-ray diffraction (XRD), differential scanning calorimetry (DSC), vibrating sample magnetometry (VSM), and energy dispersive X-ray spectroscopy (EDX), the morphology, crystal phase, thermal stability, magnetization properties, and chemical structure of the fabrics were examined. Measurements were also taken of the treated fabrics' colorimetric values and tensile characteristics. Fe_3O_4 and α-Fe_2O_3 nanoparticles, with mean crystal diameters of approximately 11 and 17 nm, were discovered to be produced on the fabrics treated at 130°C and boiling point, respectively. SEM and EDX confirmed that the iron oxide nanoparticles were uniformly distributed on the fiber surface. Furthermore, reflectance spectra showed that the iron oxide nanoparticles had various coloring impacts on the treated fabrics. Reasonable saturation magnetization values of around 7.5 and 0.1 emu g^{-1}, respectively, were observed in the magnetite and hematite treated samples. Remarkably, when compared to the untreated fabric, the treated samples' tensile qualities were improved. These results point to the possibility of using the suggested method to produce fabrics with strong magnetic properties, particularly for electromagnetic shielding, good antibacterial activity against Staphylococcus aureus, and promising sono-Fenton catalytic ability for discoloration of dyes. These fabrics could be used for a variety of purposes. [86]

Use of zinc oxide nano particles for production of antimicrobial textiles

An developing field in nanoscience and nanotechnology is the application of materials and structures at the nanoscale, which are typically measured in nanometers (nm) between 1 and 100. There is ongoing interest in the synthesis of noble metal nanoparticles for use in biology, electronics, textiles, environmental protection, and catalysis, among other applications. Antimicrobial fabrics have recently been developed as a result of increased awareness of personal protection, contact disease transmission, and general sanitation. In this work, the development of antimicrobial cotton fabrics with zinc oxide nanoparticles has been studied. Using the pad-dry-cure approach, ZnO nanoparticles were directly placed to 100% cotton woven fabric after being manufactured by a wet chemical method. The agar diffusion and parallel streak methods were used to qualitatively evaluate the antibacterial activity of the completed fabrics, and the percentage decrease test was used to quantify it. The treated and untreated fabrics' topographical analyses were examined and contrasted. Both qualitative and quantitative testing reveal that the completed cloth had strong antibacterial activity against S. aureus. ZnO nanoparticles were embedded in the treated fabrics, as shown by the SEM study. The treated fabric was proven to endure up to 25 wash cycles in a study on wash durability. [87]

Preparing textiles against bacteria using plant extracts

Antibacterial Finishing of Cotton Fabric Using Stinging Nettle (Urtica dioica L.) Plant Leaf Extract:

Natural organic fibers such as cotton, linen, and wool are readily attacked by microorganisms. Microbial growth on a textile fabric causes loss of strength and elongation, discoloration, and changes in appearance. The antibacterial finishing agents extracted from nettle plant leaf have been used to impart finish to the cotton fabric by using the Pad-Dry-Cure application method. The antibacterial activity of the finish was assessed quantitatively using the AATCC 100:2004 test method, and the antibacterial activity against Gram-positive (Staphylococcus aureus) and Gram-negative (Escherichia coli) bacteria was measured. There was a 100 to 99.75 percent reduction in the count of test bacteria. Physical properties of treated and untreated cotton fabrics such as absorbency, fabric stiffness, air permeability, and strength were analyzed. To evaluate the laundering effect of stinging nettle leaf finished fabric, samples were subjected to laundry with 5, 10, 15, 20, 25, 30, 35, and 40 washing cycles using standard AATCC test method 61, and bacterial count of treated samples was tested. The results showed gradual decrease in antibacterial property, with a 100 to 44% reduction in the bacterial count for Staphylococcus aureus and a 100 to 30% reduction in the bacterial count for Escherichia coli. The results of this investigation suggested that nettle leaf, a low-cost abundant plant in Ethiopia, can be used for antibacterial activity in woven cotton fabric. [88]

Experimental study on antimicrobial activity of cotton fabric treated with aloe gel extract from Aloe vera plant for controlling the Staphylococcus aureus (bacterium)

Biotechnology is a cutting-edge field of science and technology with major global commercial applications in the healthcare, agricultural, process, and service industries. Ethiopia's distinct advantages put it in a position to capitalize on the potential of biotechnology. These characteristics iinclud availability of advanced technology, trained labor, abundant biological resources, and a progressive political ssyste regulations. Additionally, the nation is quickly becoming a significant biotech product market. Now, ffres In many domains of study and industry, biotechnology is closely associated with processes and products The textile sector also offers the widest range of opportunities for its commercial application. In this investigation to create antimicrobial cloth, aloe gel has been added to 100% cotton fabric. To maximize the method parameter, cotton fabric underwent treatment using extract from aloe vera (Aloe barbadensis Mill) at different concentrations of 1, 2, 3, and 5 gpl using the pad-dry-cure procedure for 30 minutes at 60°C. Methanol was employed as a solvent when extracting aloe gel from the Aloe vera plant. Samples of the completed cloth have undergone testing for activity using the quantitative analysis test method and the ATCC (Agar diffusion) method. The aalo Textiles treated with gel shown antibacterial efficacy against ATCC 6538 strains of Staphylococcus aureus. The Excellent antibacterial activity has been demonstrated in treated cotton materials at 5 gpl concentration. The cleaning Even after 50 washes, the treated sample's durability was judged to be good. [89]

Antibacterial finish for cotton fabric from herbal products

An ecofriendly natural antibacterial finish has been prepared from the plant extracts for textile application. Herbal extracts from Ocimum sanctum (tulsi leaf) and rind of Punica granatum (pomegranate) have been applied to cotton fabric by the method of direct application, micro-encapsulation, resin cross-linking and their combinations. All the treatments show good antibacterial properties for the fabrics. Except the method of direct application, all other treatments show good washing durability up to 15 washes. The surface morphological studies using SEM show the surface coating, microcapsules and some fibrillation. The GC-MS studies reveal that the major components responsible for the antibacterial properties are Eugenol, Germacrene and Phytol. A small decrease in tensile strength and crease recovery angle is observed for resin treated and micro-encapsulated fabrics respectively. But No notable changes are seen in the combined procedures. [90]

Eco-friendly antimicrobial finishing of cotton fabrics using bioactive agents from novel Melia azedarachayan berries extract and their performance after subsequent washings

Antibacterial fabrics are now crucial for controlling and organizing microbial infestations as well as minimizing the development of unpleasant odors. When textiles with antimicrobial finishes are consumed by humans, their continued efficacy after every wash is the main cause for worry. Numerous benefits come with cotton fabric, including compatibility, absorbency, superior dimensional stability, and less shrinkage. The fact that the germs on them cause them to deteriorate is one of their main disadvantages. We have made natural and organic extracts from the peels of the wild tree Melia azedarachayan, also known as Bakaayan, plant berry in order to assess antimicrobial activity. After the Bakaayan berries were preserved in ethyl acetate for two weeks, a berry pitch was produced using the After the fabric was subjected to the distillation process and padded, the anti-microbial properties were examined by looking at the growth of bacteria on the cloth 24 hours later. The recovered pitch was discovered to be antibacterial after bacterial growth on fabric was examined under a microscope. In a study, both qualitative and quantitative analysis was used to assess the fabric samples' antimicrobial effectiveness against bacterial strains such as Staphylococcus, E. coli, Bacillus, and Candida albicans. With the exception of Candida albicans, the study's findings suggest that cotton fabric has superior microbiological resistance against the strains listed above. The cloth treated with anti-microbial extract had the highest decrease against Staphylococcus, according to quantitative study. In order to examine how washing affected the antimicrobial activity, the completed fabrics were cleaned in accordance with ISO 6330 standard. With each wash, the antibacterial activity gradually decreases, according to the washing outcome. [91]

Conclusion

Synthetic and natural fabrics have been used to obial textiles. Antimicrobial develop antimicr properties can be provided by the application of chemicals, environmentally friendly materials and other technologies such as plasma, supercritical nano and microencapsulations. Synthetic chemicals ased on them are and antimicrobial textiles b effective but also appear to pose a threat towards harming the environment as there is very limited information available about the exact effect of chemicals that can leach into the environment. d Therefore, future research should be directe towards exploring the potential of natural antimicrobial agents and using modern technologies that are less harmful to the environment.

Conflict of Interest

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

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References

1. Hassabo, A.G., Abd El-Salam, N.A., Mohamed, N.A., Gouda, N.Z. and Othman, H. Potential application of natural gums suitable as thickeners in textile printing, *J. Text. Color. Polym. Sci.*, **20**(1) 57-65 (2023).
2. Ahmed, N., Shahin, A., Othman, H. and Hassabo, A.G. Neem tree extracts used in textile industries, *Egy. J. Chem.*, **67**(13) 159-169 (2024).
3. Elmansy, M.F., Mohamed, A.L., Gaffer, H. and Hassabo, A.G. Extraction, characterization, and utilization of tea leaf extract in textile wet process, *J. Text. Color. Polym. Sci.*, **22** 111-124 (2025).
4. Mohamed, A.L., Hassabo, A.G., Nada, A.A. and Abou-Zeid, N.Y. Properties of cellulosic fabrics treated by water-repellent emulsions, *Indian J. Fibre Text. Res.*, **42**(June) 223-229 (2017).
5. Hassabo, A.G., Reda, E.M., Ghazal, H. and Othman, H.A. Synthesis of agnps and znonps using tea leaves extract and their utilization to improve dyeability, printability and functionality of cotton and wool fabrics, *Inorg. Chem. Commun.*, **150** 110525 (2023).
6. Hamdy, D.M., Hassabo, A.G. and Othman, H. Recent use of natural thickeners in the printing process, *J. Text. Color. Polym. Sci.*, **18**(2) 75-81 (2021).
7. Saad, F., Mosaad, M.M., Othman, H.A., Mohamed, A.L. and Hassabo, A.G. Enhancing the opacity of the modified natural thickening agent with different metal oxides for covering dark dyed fabrics, *Fibers and Polymers*, EMID:4f46efe6ab478977 (2022).
8. Saad, F., Mohamed, A.L., Mosaad, M., Othman, H.A. and Hassabo, A.G. Enhancing the rheological properties of aloe vera polysaccharide gel for use as an eco-friendly thickening agent in textile printing paste, *Carbo. Polym. Technol. App.*, **2** 100132 (2021).
9. El-Sayed, G.A., Diaa, M., Othman, H.A. and Hassabo, A.G. Potential uses of aloe vera extract in textile wet process, *J. Text. Color. Polym. Sci.*, **18**(2) 159-169 (2021).
10. Sathianarayanan, M.P., Bhat, N.V., Kokate, S.S. and Walunj, V.E. Antibacterial finish for cotton fabric from herbal products, *Indian J. Fibre Text. Res.*, **35**(1) 50-58 (2010).
11. Tiwari, V., Ghorpade, B., Mishra, A. and Vanka, P.S. Utrasonic dyeing with ocimum sanctum (tulsi leaves) with eco-friendly mordants, *New Cloth Market*, **23**(1) 23-24 (2000).
12. Negi, A. and Kesari, K.K. Chitosan nanoparticle encapsulation of antibacterial essential oils, *Micromachines (Basel)*, **13**(8) (2022).
13. Vaideki, K. Plasma technology for antimicrobial textiles, Antimicrobial textiles, Elsevierpp. 73-86, (2016).
14. Murugesh Babu, K. and Ravindra, K. Bioactive antimicrobial agents for finishing of textiles for health care products, *The Journal of The Textile Institute*, **106**(7) 706-717 (2015).
15. Ghazal, H., Khaleed, N., Shaker, S. and Hassabo, A.G. An overview of the dyeing process of lyocell fabric and its blends, *J. Text. Color. Polym. Sci.*, **21**(1) 49-62 (2024).
16. Abd El-Aziz, E., Ezat, H.A., Abd El-Rahman, R., abdelraouff, A., El-Desoky, S.S., El-Bahrawy, G.A. and Hassabo, A.G. Improve the quality of coloring performance of silk fabric, *J. Text. Color. Polym. Sci.*, **21**(1) 11-22 (2024).
17. Soliman, M.Y., Othman, H.A. and Hassabo, A.G. A recent study for printing polyester fabric with different techniques, *J. Text. Color. Polym. Sci.*, **18**(2) 247-252 (2021).
18. Ragab, M.M., Othman, H.A. and Hassabo, A.G. Resist and discharge printing techniques on different textile based materials, *J. Text. Color. Polym. Sci.*, **18**(2) 229-237 (2021).
19. Roy Maulik, S., Chakraborty, L. and Pandit, P. Evaluation of cellulosic and protein fibers for coloring and functional finishing properties using simultaneous method with eucalyptus bark extract as a natural dye, *Fibers and Polymers*, **22**(3) 711-719 (2021).
20. Yılmaz, F. Investigating the usage of eucalyptus leaves in antibacterial finishing of textiles against gram-positive and gram-negative bacteria, *J. Text. Inst.*, **112**(2) 341-345 (2021).
21. Kriegeskorte, N. and Diedrichsen, J. Peeling the onion of brain representation, *Annual Review of Neuroscience*, **42** 25 (2019).
22. Ju, A. and Song, K.B. Incorporation of yellow onion peel extract into the funoran-based biodegradable films as an antioxidant packaging material, *Int. J. Food Sci. Technol.*, **55**(4) 1671-1678 (2020).
23. Mohan, R., N, G., D, H.J. and Sivakumar, V. Studies on natural dye (pelargonidin) extraction from onion peel and application in dyeing of

leather, *International Journal of Recent Engineering Science*, **7**(1) 12-16 (2020).

24. Ragab, M.M., Hassabo, A.G. and Othman, H.A. An overview of natural dyes extraction techniques for valuable utilization on textile fabrics, *J. Text. Color. Polym. Sci.*, **19**(2) 137-153 (2022).

25. Abdel-Aziz, E., Bakr, M., Zayed, M., Othman, H. and Hassabo, A.G.J. Microencapsulation and its application in textile wet processing: A review, *Journal of Textiles, Coloration Polymer Science*, **19**(2) 189-202 (2022).

26. Boh Podgornik, B., Šandrić, S. and Kert, M. Microencapsulation for functional textile coatings with emphasis on biodegradability—a systematic review, *Coatings*, **11**(11) 1371 (2021).

27. Nadi, A., Boukhriss, A., Bentis, A., Jabrane, E. and Gmouh, S. Evolution in the surface modification of textiles: A review, *Textile Progress*, **50**(2) 67-108 (2018).

28. Petrova, L., Yaminzoda, Z., Odintsova, O., Vladimirtseva, E., Solov'eva, A. and Smirnova, A. Promising methods of antibacterial finishing of textile materials, *Russian Journal of General Chemistry*, **91**(12) 2758-2767 (2021).

29. Tania, I.S., Ali, M. and Arafat, M.T. Processing techniques of antimicrobial textiles, Antimicrobial textiles from natural resources, Elsevierpp. 189-215, (2021).

30. Beşen, B.S. Tea tree oil/ethyl cellulose microcapsule loaded antimicrobial textiles, *AATCC Journal of Research*, **7**(2) 1-6 (2020).

31. Nada, A.A., Abd El-Azeem, R.A., Hassabo, A.G., Mohamed, A.L., Ibrahim, H.M., Fayad, W. and Abou-Zeid, N.Y. Encapsulation of ricinoleic acid into electrospun ethyl cellulose fibers, 11th International Conference on Nanosciences & Nanotechnologies – NN14, Porto Palace Conference Centre & Hotel, Thessaloniki, Greece, (2014).

32. Mohamed, A.L., Hassabo, A.G., Nada, A.A. and Zaghlool, S. Encapsulation of nicotinamide into cellulose based electrospun fibres, *JAPS*, **6**(8) 13-21 (2016).

33. El-Naggar, M.E., Hassabo, A.G., Mohamed, A.L. and Shaheen, T.I. Surface modification of sio2 coated ZnO nanoparticles for multifunctional cotton fabrics, *J. Colloid Interface Sci.*, **498** 413-422 (2017).

34. Fahmy, H.M., Okda, H.M.Y., Hassabo, A.G., El-Rafie, M.H. and Youssef, M.A. Synthesis of new silicone-based adducts to functionalize cotton fabric, *Silicon*, (2021).

35. Kamel, M.Y. and Hassabo, A.G. Anti-microbial finishing for natural textile fabrics, *J. Text. Color. Polym. Sci.*, **18**(2) 83-95 (2021).

36. Yousef, M.Y. and Hassabo, A.G. Environmentally friendly inorganic materials for anti-flammable cotton fabrics, *J. Text. Color. Polym. Sci.*, **18**(2) 97-110 (2021).

37. Fahmy, H., Okda, h., elrafie, M., Hassabo, A.G. and youssef, m.a. Synthesis and application of new silicone based water repellents, *Egy. J. Chem.*, **65**(2) 499-507 (2022).

38. Hassabo, A.G., Zayed, M.T., Bakr, M. and Othman, H.A. The utilisation of gelatin biopolymer in textile wet processing, *J. Text. Color. Polym. Sci.*, **19**(2) 125-136 (2022).

39. Zayed, M., Othman, H., Ghazal, H. and Hassabo, A.G. A valuable observation on natural plants extracts for valuable functionalization of cotton fabric (an overview), *Egy. J. Chem.*, **65**(4) 499 – 524 (2022).

40. Abdel Salam, K.A., Ibrahim, N.A., Maamoun, D., Abdel Salam, S.H., Fathallah, A.I., Abdelrahman, M.S., Mashaly, H., Hassabo, A.G. and Khattab, T.A. Anti-microbial finishing of polyamide fabric using titanium dioxide nanoparticles, *J. Text. Color. Polym. Sci.*, **20**(2) 171-174 (2023).

41. Attia, E.F., Helal, T.W., Fahmy, L.M., Wahib, M.A., Saad, M.M., Abd El-Salam, S., Maamoun, D., Mahmoud, S.A., Hassabo, A.G. and Khattab, T.A. Antibacterial, self-cleaning, UV protection and water repellent finishing of polyester fabric for children wheelchair, *J. Text. Color. Polym. Sci.*, **20**(2) 181-188 (2023).

42. Tarek, D., Mohmoud, A., Essam, Z., Sayed, R., Maher, A., Maamoun, D., Abdel Salam, S.H., Mohamed, H., Hassabo, A.G. and Khattab, T.A. Development of wrinkle free and self-cleaning finishing of cotton and polyester fabrics, *J. Text. Color. Polym. Sci.*, **20**(2) 175-180 (2023).

43. Al-Gizawy, A.S.H., Al-Minyawi, O.M.A., Mahmoud, M.N.I., Ragab, A.G. and Hassabo, A.G. Significant relationship between pre-treatments and environmentally safe anti-combustion preparation in enhancing appearance properties of cotton fabrics&quot, *J. Text. Color. Polym. Sci.*, - (2024).

44. Gaafar, Z.S., Roshdy, Y.A.E.-m., El-Shamy, M.N., Mohamed, H.A. and Hassabo, A.G. Antimicrobial processing techniques for fabric enhancement, *J. Text. Color. Polym. Sci.*, - (2024).

45. Reda, E.M., Othman, H. and Hassabo, A.G. Usage of natural resources in textile wet processes, *J. Text. Color. Polym. Sci.*, - (2024).

46. Ferrero, F., Periolatto, M.J.J.o.n. and nanotechnology Antimicrobial finish of textiles by chitosan UV-curing, **12**(6) 4803-4810 (2012).

47. Hasan, K.F., Hridam, D., Rahman, M.M., Morshed, M.N., Al Azad, S., Genyang, C.J.A.J.o.P.S. and Engineering A review on antibacterial coloration agent's activity, implementation & efficiency to ensure the ecofriendly & green textiles, **4**(1) 39-59 (2016).

48. Morais, D.S., Guedes, R.M. and Lopes, M.A.J.M. Antimicrobial approaches for textiles: From research to market, **9**(6) 498 (2016).

49. El-Sayed, E. and Hassabo, A.G. Recent advances in the application of plasma in textile finishing, *J. Text. Color. Polym. Sci.*, **18**(1) 33-43 (2021).

50. Abdel-Aziz, E., Bakr, M., Zayed, M., Othman, H. and Hassabo, A.G. Microencapsulation and its application in textile wet processing: A review, *J. Text. Color. Polym. Sci.*, **19**(2) 189-202 (2022).

51. Hamdy, D.M., Othman, H.A. and Hassabo, A.G. A recent uses of plasma in the textile printing *J. Text. Color. Polym. Sci.*, **19**(1) 1-10 (2022).

52. Hassabo, A.G., Zayed, M., Bakr, M. and Othman, H.A. Review on some fabric pretreatment via plasma to improve their printability using various types of colorants and dyes, *Materials International*, **4**(3) 1-16 (2023).

53. Mamdouh, F., Othman, H. and Hassabo, A.G. Improving the performance properties of polyester fabrics through treatments with natural polymers, *J. Text. Color. Polym. Sci.*, - (2024).

54. Zakaria, N., Shahin, A., Othman, H. and Hassabo, A.G. Enhancing the properties of textile fabrics using plasma technology, *Egy. J. Chem.*, **67**(13) 171-177 (2024).

55. Shahidi, S., Ghoranneviss, M. and Moazzenchi, B. New advances in plasma technology for textile, *Journal of Fusion Energy*, **33** 97-102 (2014).

56. Chang, Y.-B., Tu, P.-C., Wu, M.-W., Hsueh, T.-H., Hsu, S.-h.J.F. and Polymers A study on chitosan modification of polyester fabrics by atmospheric pressure plasma and its antibacterial effects, **9** 307-311 (2008).

57. Deng, X. Atmospheric pressure plasma jet for the deposition of nanocomposite antibacterial coatings, Ghent University, (2015).

58. Nikiforov, A.Y., Deng, X., Onyshchenko, I., Vujosevic, D., Vuksanovic, V., Cvelbar, U., De Geyter, N., Morent, R. and Leys, C.J.T.E.P.J.A.P. Atmospheric pressure plasma deposition of antimicrobial coatings on non-woven textiles, **75**(2) 24710 (2016).

59. Ibrahim, N.A., Eid, B.M. and Abdel-Aziz, M.S. Effect of plasma superficial treatments on antibacterial functionalization and coloration of cellulosic fabrics, *Applied Surface Science*, **392** 1126-1133 (2017).

60. Shahidi, S., Ghoranneviss, M., Moazzenchi, B., Rashidi, A. and Mirjalili, M. Investigation of antibacterial activity on cotton fabrics with cold plasma in the presence of a magnetic field, *Plasma Processes Polymers*, **4**(S1) S1098-S1103 (2007).

61. Zizovic, I. Potential of supercritical solvent impregnation for development of materials with antibacterial properties, *Int. Arch. Med. Microbiol*, **1** 1-6 (2017).

62. Abate, M.T., Ferri, A., Guan, J., Chen, G., Ferreira, J.A. and Nierstrasz, V. Single-step disperse dyeing and antimicrobial functionalization of polyester fabric with chitosan and derivative in supercritical carbon dioxide, *The Journal of Supercritical Fluids*, **147** 231-240 (2019).

63. Markovic, D., Milovanovic, S., Radetic, M., Jokic, B. and Zizovic, I. Impregnation of corona modified polypropylene non-woven material with thymol in supercritical carbon dioxide for antimicrobial application, *The Journal of Supercritical Fluids*, **101** 215-221 (2015).

64. Abou Elmaaty, T., Ma, J., El-Taweel, F., Abd El-Aziz, E. and Okubayashi, S. Facile bifunctional dyeing of polyester under supercritical carbon dioxide medium with new antibacterial hydrazono propanenitrile dyes, *Industrial Engineering Chemistry Research*, **53**(40) 15566-15570 (2014).

65. Gittard, S.D., Hojo, D., Hyde, G.K., Scarel, G., Narayan, R.J., Parsons, G.N.J.J.o.M.E. and Performance Antifungal textiles formed using silver deposition in supercritical carbon dioxide, **19** 368-373 (2010).

66. Hassabo, A.G., Mohamed, A.L., Nada, A.A. and Zeid, N.Y.A. Controlled release of drugs from cellulosic wound bandage using silica microsphere as drug encapsulator module, *JAPS*, **5**(12) 067-073 (2015).

67. Hassabo, A.G., Mohamed, A.L., Wang, H., Popescu, C. and Moller, M. Metal salts rented in silica microcapsules as inorganic phase change materials for textile usage, *Inorganic Chemistry: An Indian Journal*, **10**(2) 59-65 (2015).

68. Hassabo, A.G. and Mohamed, A.L. Enhancement the thermo-regulating property of cellulosic fabric using encapsulated paraffins in modified pectin, *Carbohydrate Polymers*, **165** 421-428 (2017).

69. El-Wekil, A.N., Marey, A.G., Allam, L.N., Abd-Elaal, L.S. and Hassabo, A.G. Micro/nano capsulation: Textile functional features and application, *J. Text. Color. Polym. Sci.*, - (2024).

70. El-Zawahry, M.M., Kamel, M.M. and Hassabo, A.G. Development of bio-active cotton fabric coated with betalain extract as encapsulating agent for active packaging textiles, *Indust. Crop. Prod.*, **222** 119583 (2024).

71. Marey, A.G., Allam, L.N., Abd-Elaal, L.S., El-Wekil, A.N. and Hassabo, A.G. The applications of microencapsulation in different textile finishing, *J. Text. Color. Polym. Sci.*, - (2024).

72. Mohamed, H.A., Gaafar, Z.S., Roshdy, Y.A.E.-m., El-Shamy, M.N. and Hassabo, A.G. Microencapsulation and its application in textile industry, *J. Text. Color. Polym. Sci.*, **22** 81-87 (2025).

73. Muñoz, V., Gonzalez, J.S., Martínez, M.A. and Alvarez, V.A. Functional textiles for skin care active substance encapsulation, *Journal of Textile Engineering & Fashion Technology*, **2** 1-8 (2017).

74. Saraswathi, R., Krishnan, P. and Dilip, C.J.A.P.J.o.T.M. Antimicrobial activity of cotton and silk fabric with herbal extract by micro encapsulation, **3**(2) 128-132 (2010).

75. Yaman Turan, N., Turker, E. and Insaatci, Ö. Microparticles loaded with propolis to make antibacterial cotton, *Cellulose*, **28** 4469-4483 (2021).

76. Sharkawy, A., Fernandes, I.P., Barreiro, M.F., Rodrigues, A.E., Shoeib, T.J.I. and Research, E.C. Aroma-loaded microcapsules with antibacterial activity for eco-friendly textile application: Synthesis, characterization, release, and green grafting, **56**(19) 5516-5526 (2017).

77. Liu, J., Liu, C., Liu, Y., Chen, M., Hu, Y. and Yang, Z. Study on the grafting of chitosan–gelatin microcapsules onto cotton fabrics and its antibacterial effect, *Colloids Surfaces B: Biointerfaces*, **109** 103-108 (2013).

78. Wijesirigunawardana, P.B. and Perera, B.G.K. Development of a cotton smart textile with medicinal properties using lime oil microcapsules, *Acta Chim. Slov*, **65**(1) 150-159 (2018).

79. Yang, Z.M., Liang, G.Q., Li, L., Au, W.M., Zhong, H.Y., Wong, T.K. and Yang, Z.H. Preparation of antibacterial cotton fabric containing patchouli oil microcapsules by chemical crosslinking method, *Advanced Materials Research*, **221** 308-315 (2011).

80. Liu, C.H., Zhou, H.J., Liu, J.Y., Li, X.T., Fang, H. and Yang, Z.H. Preparation of antibacterial citronella oil microcapsules and their application in cotton fabrics, *Advanced Materials Research*, **627** 271-274 (2013).

81. Joshi, M. and Bhattacharyya, A. Nanotechnology–a new route to high-performance functional textiles, *Textile progress*, **43**(3) 155-233 (2011).

82. Asokan, A., Ramachandran, T., Ramaswamy, R., Koushik, C. and Muthusamy, M. Preparation and characterization of zinc oxide nanoparticles and a study of the anti-microbial property of cotton fabric treated with the particles, *Journal of Textile Apparel, Technology Management*, **6**(4) (2010).

83. El-Nahhal, I.M., Zourab, S.M., Kodeh, F.S., Selmane, M., Genois, I. and Babonneau, F. Nanostructured copper oxide-cotton fibers: Synthesis, characterization, and applications, *International nano letters*, **2** 1-5 (2012).

84. dos Santos, O.A.L., de Araujo, I., da Silva, F.D., Sales, M.N., Christoffolete, M.A. and Backx, B.P. Surface modification of textiles by green nanotechnology against pathogenic microorganisms, *Current Research in Green Sustainable Chemistry*, **4** 100206 (2021).

85. Anwar, Y., Ullah, I., Ul-Islam, M., Alghamdi, K.M., Khalil, A. and Kamal, T.J.A.J.o.C. Adopting a green method for the synthesis of gold nanoparticles on cotton cloth for antimicrobial and environmental applications, **14**(9) 103327 (2021).

86. Harifi, T. and Montazer, M. In situ synthesis of iron oxide nanoparticles on polyester fabric utilizing color, magnetic, antibacterial and sono-fenton catalytic properties, *Journal of Materials Chemistry B*, **2**(3) 272-282 (2014).

87. Rajendra, R., Balakumar, C., Ahammed, H.A.M., Jayakumar, S., Vaideki, K. and Rajesh, E. Use of zinc oxide nano particles for production of antimicrobial textiles, *International Journal of Engineering, Science Technology*, **2**(1) 202-208 (2010).

88. Ketema, A. and Worku, A.J.J.o.C. Antibacterial finishing of cotton fabric using stinging nettle (urtica dioica l.) plant leaf extract, **2020** 1-10 (2020).

89. Jothi, D. Experimental study on antimicrobial activity of cotton fabric treated with aloe gel extract from aloe vera plant for controlling the staphylococcus aureus (bacterium), *African Journal of Microbiology Research*, **3**(5) 228-232 (2009).

90. Sathianarayanan, M., Bhat, N., Kokate, S. and Walunj, V. Antibacterial finish for cotton fabric from herbal products, (2010).

91. Syed, M.H., Qutaba, S., Zahari, M.A.K.M., Abdullah, N., Shoaib, M., Bashir, H.F., Ali, M.Q., Ali, R., Iqbal, A. and Ali, W. Eco-friendly antimicrobial finishing of cotton fabrics using bioactive agents from novel melia azedarachayan berries extract and their performance after subsequent washings, *Egyptian Journal of Chemistry*, **66**(11) 255-268 (2023).