Journal of Textiles, Coloration and Polymer Science
https://jtcps.journals.ekb.eg/
Egyptian Society for Textile Science and Technology
الجمعية المصرية لعلوم وتكنولوجيا النسيج

Advancements in polymer nanocomposites: synthesis, characteristics, and future potential

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Abstract

Material science is becoming more popular and useful, with a significant demand for composite materials that incorporate the finest attributes of both components. Polymer nanocomposites have recently created quite a stir in the media and in a variety of industries. There has been a lot of interest in modifying the structure and composition of materials on a nanometre scale all across the world in recent years. As a result, a thorough examination of the production, properties, and applications of polymer nanocomposites is essential. Polymer nanocomposites are classified into numerous types depending on a variety of characteristics. The sol gel method, in-situ polymerisation, solution mixing, melt mixing, and in-situ intercalative polymerisation are all utilized in the preparation. Nanocomposites' mechanical, optical, rheological, flame retardancy, and dielectric properties have all been extensively researched. Finally, the important applications of nanocomposites have been explored, as well as their future potential.

Keywords: Nanotechnology , synthesis, NanoPolymer , Application

Introduction

Nanotechnology is the method of modifying the shape and size of structures, electronics, and systems at the nanometer scale 1 nm to 100 nm (10^{-9}m) or the science of tiny objects with sizes smaller than 100 nm see Figure 1 and Figure 2[1, 2].

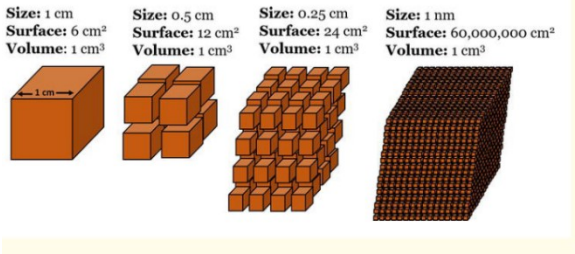

Figure 1: Surface-to-volume ratio of nanoparticles compared with that of bulk materials

Researchers have shown that materials at very small sizes, such thin films and nanoparticles, may differ greatly from materials at very large sizes[3, 4]. These unique qualities have fueled the development of nanoscience and the use of NPs in a variety of industries, including paints, cosmetics, biomedicine, electronics, food analysis, environmental cleanup, and cosmetics[5, 6].

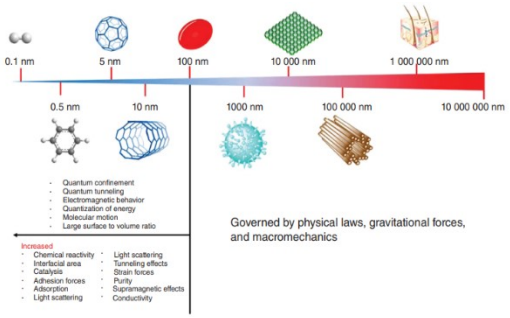

Figure 2: Nanomaterials peculiarities of size scale

Nanoscience is one of the more important research disciplines in modern science. Nanotechnology is enabling researchers to work at the molecular and cellular levels, resulting in significant advances in life sciences and healthcare[7-11].

Nanofibrous textiles are textiles made up of nanoscale fibers. The first commercial application of nano finishing materials in textiles is in the form of nanoparticles. However, due to the poor attachment of these nanoparticles on the textile surface, these finishes do not withstand repeated washing, hence nanocomposites can offer improved multiple functions by overcoming the constraints associated with conventional materials[12].

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Receive Date: 31 December 2023, Accept Date: 24 February 2024
DOI: 10.21608/jtcps.2024.259622.1306

Methods of synthesis of nanomaterials

The qualities of materials influence their performance. The properties of tern are determined by the atomic structure, composition, microstructure, defects, and interfaces, which are governed by the synthesis's thermodynamics and kinetics.

Classification of Techniques for synthesis of Nanomaterials

The synthesis of nanomaterials can be done in two general ways see **Error! Reference source not found.**:

a) Top- down approach

b) Bottom–up approach.

Top- down approach

In a top-down method, the bulk material is broken down into particles or structures that are nanoscale.

Techniques to generate micron-sized particles have been expanded upon by top-down synthesis. Top-down techniques are simpler by nature and rely on either miniaturizing bulk production procedures or dividing or removing bulk material in order to produce the desired structure with the right attributes[13].

Bottom–up approach

Bottom-up approaches refer to the construction of a material from the ground up, atom by atom, molecule by molecule, or cluster by cluster see **Error! Reference source not found.**.This technique is used in printing and finishing textiles.

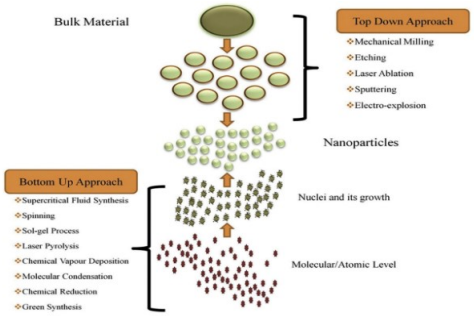

Figure 2: Schematic representation of 'top-down' and 'bottom-up' approaches for synthesis of nanoscale materials[14]

Polymer Nanocomposites

Polymer nanocomposites (PNCs) are polymer-nanomaterial blends with at least one-dimensional structure and one component material with a nanometer size smaller than 100 nm. Combining nanomaterials into the polymer matrix not only produces a new class of properties provided by uniformly dispersed nanomaterials, but it additionally significantly enhances most of the original polymer's expected properties, such as mechanical properties, heat resistance, biodegradability, and more[15].

Types of polymers

Polymer nanocomposites are classified into two types based on the sort of polymer used:

- biodegradable polymer.
- non-biodegradable polymer

biodegradable polymer nanocomposites

Nowadays, especially as a result of the global pollution problem, there's a tendency toward the search for and use of biodegradable polymers, polymeric compounds, and polymeric nanocomposites. The main characteristic and benefit of biodegradable polymers is that, once they stop degrading, their polymer chains tend to break down into simpler molecules and structures than the original structure due to bacteria, radiation, oxygen, and other factors[16].

As the polymer chains deteriorate, the articles made from these materials are broken and disintegrated into small fragments that cause minor damage to the environment. In some cases, depending on the polymer, the degradation products can arrive to be beneficial to the environment where disintegration occurs. Biopolymers are an example of this because, as part of a compost structure, the chemicals from the decomposition may benefit the environment.

In general, polymers can be classified into the following 3 categories[17]:

Biodegradable natural polymers

Because they are created by living creatures and are entirely biodegradable and renewable, these natural polymers are also known as ecologically degradable polymers. Polymers are classed as follows: polysaccharides (for example, starch), chitosan[17-21].

Biodegradable synthetic polymers

They are biodegradable polymers that can be decomposed by enzymes. This class of material includes aliphatic polyesters, which can be hydrolyzed by lipases and esterase, and poly (caprolactone) (PCL), which can be destroyed by the activity of Penicillium spp. PCL is a popular polymer for making biodegradable synthetic polymer nanocomposites[18].

Biodegradable polymer blends

This category includes materials that are the result of mixing biodegradable and non-biodegradable polymers. These materials are biodegradable, and they are less expensive than pure biodegradable natural polymers. Examples include those manufac-

tured by combining low density polyethylene with starch or poly (3-hydroxybutyrate), where the presence of the biodegradable polymer allows for partial biodegradation, making the combination a viable option to totally biodegradable polymers[18].

Non-biodegradable polymer

They are polymers that, as their title implies, are not broken down into simpler molecules by biological processes and, as a result of their proclivity to remain intact over time, are causing harm to our environment. Polyethylene terephthalate, polypropylene, and polystyrene are examples of non-biodegradable polymers.

The Properties of Polymer Nanocomposites

Many features of the original polymer, as well as new qualities coming from the addition of nanoparticles, can be considerably improved in PNCs see **Figure 3**.

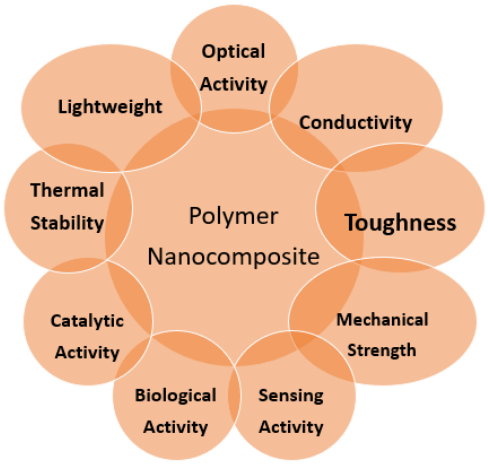

Figure 3: Significant properties of polymer nanocomposites

Synthesis of Polymer Nanocomposites

To achieve the functionalities of fillers, it is required to equally distribute the fillers into the matrix during PNC synthesis. However, because the fillers are nanoscale, the uniform dispersion is significantly different from that of microscale fillers, as shown in the following features. First, if the filling process is performed according to volume fraction, substantially more nanometer fillers are required than microfillers at the same volume fraction. As a result, the nanoparticles in the matrix are more crowded, with higher van der Waals and electrostatic interactions between the particles, making uniform distribution impossible. Second, anisotropic nanofillers have a very high aspect ratio, making them highly effective.

i) Ultrasonication-assisted Solution Mixing

Ultrasonication-assisted solution mixing is the most often utilized method for producing PNCs. The nanofillers and polymer are first dissolved in a solution in this process. The nanofillers are then evenly disseminated throughout the matrix with the use of ultrasound. The PNCs are then produced by evaporating the solvent[22, 23].

The ultrasonic energy, which is greater than the energy of interaction among the nanomaterials in the aggregates, separates the nanoparticles from the agglomeration state and separates them into smaller pieces. The aggregates of nanofillers are broken down into smaller ones as the ultrasonic time increases, and eventually become individual nanoparticles independent of other nanoparticles in the polymer. Furthermore, this technique is frequently carried out at high temperatures, which might commence in situ polymerization of reactive monomers or their soluble prepolymers with nanomaterials in order to improve interfacial interactions[23, 24].

ii) Shear Mixing

Shear mixing, as opposed to ultrasonic-assisted mixing, is a far more common and easy technology that only requires the stirring process and has the potential for industrial mass production. The shear force created by the stirrer turning is employed to separate the aggregates of nanofillers during the stirring operation.Because of the low shear force, the nanoparticles will be separated under stirring and then aggregated again, therefore the agitator speed must be increased to complete the separation. Because this approach does not generally disrupt the structure of nanofillers, it is appropriate not only for separating weakly bound nanoaggregates, but also for peeling off some stacked nanosheets.

iii) Three Roll Milling

Three roller milling is a method of distributing nanofillers in high viscosity matrix, such as ink, paste substance, coating, and so on, using shearing force between wheels. Three roll milling machines are made up of three cylindrical rollers that revolve at various speeds, while the neighboring rollers rotate in the opposite direction. Because the speeds of the rollers and the distance between them are changeable, the particle size distribution and homogeneity of the packing may be properly regulated. Furthermore, because the shearing force generated between the rollers is greater than that generated by stirring, the procedure can be used to high viscosity materials and performed with little or no solvent. As a result, this approach is frequently employed to disseminate anisotropic nanofillers such as CNTs[25, 26].

iv) Ball Milling

Ball milling is a common operation in the metallurgy and mineral processing industries. The objective of ball milling is to grind and combine powders in a tight space by utilizing the massive shear and compression forces generated by severe ball contact see Figure 4. This approach can disperse CNTs,

graphene nanoparticles, silica nanoparticles, and BNs into thermoplastic and thermosetting polymers during the manufacture of PNCs. Ball milling's strong shear force can peel off various two-dimensional nanostructures, such as graphene, MoS_2, and BNs, but it might not separate the interlayer structure coupled by ionic bonding [27-29]. Furthermore, because ball milling is suited for both solvent-free and solvent-containing conditions, nanofillers can be directly distributed in various solid thermoplastic matrices, such as polyethylene (PE), polyphenylene sulfide, and polymethyl methacrylate (PMMA)[30-32].

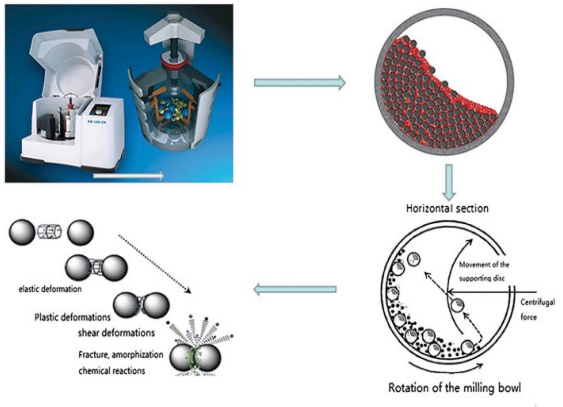

Figure 4: The principle of the ball milling method[14]

v) In Situ Synthesis

In addition to the aforementioned techniques of distributing prepared nanofillers into polymers, in situ synthesis, that synthesizes nanoparticles in polymers via molecular precursors, is an important synthesis strategy[33]. There are three common methods for obtaining nanocomposite in situ method: 1) in situ growth of nanoparticles in polymer matrix; 2) in situ polymerization of polymer in the presence of preformed nanoparticles;3) double in situ method[34].

In situ growth of nanoparticles in polymer matrix

Nanoparticles are generated from precursors in this technique, whereas the polymer matrix is preformed. Chemical reductions, photo-reductions, and acid/alkali-induced hydrolysis are all methods for preparing nanoparticles in situ see Figure 5 [35].

In situ polymerization of polymer in the presence of nanoparticles

Monomer polymerization around pre-formed nanoparticles can be used to create hybrid materials. In this process, inorganic nanoparticles are initially dispersed in monomers before being polymerized. Because of the low viscosity of the monomers, this approach may yield a homogeneous dispersion of nanoparticles[35].

Double in situ method

A two-step in situ approach has been developed, in which polymer and nanoparticles (NPs) are generated simultaneously. Nanoparticle precursors are dispersed into polymerizable monomers, and the polymer matrix is created concurrently with the NP production. As a consequence, the in-situ metal surfaces formed can accelerate or initiate polymerization by transferring electrons from metal surface atoms to monomers. It was shown to be the most efficient way for producing stable polymer-based organic-inorganic nanocomposites[34, 35].

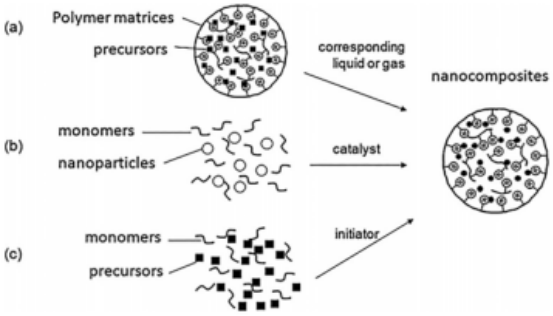

Figure 5: in situ method a) In situ growth of nanoparticles in polymer matrix, b) In situ polymerization of polymer in the presence of nanoparticles, c) Double in situ method[35]

vi) Melt blending

Polymeric nanocomposites are formed through melt processing by mixing a nanomaterial with a polymeric matrix material using conventional melt equipment like an extruder see Table 1

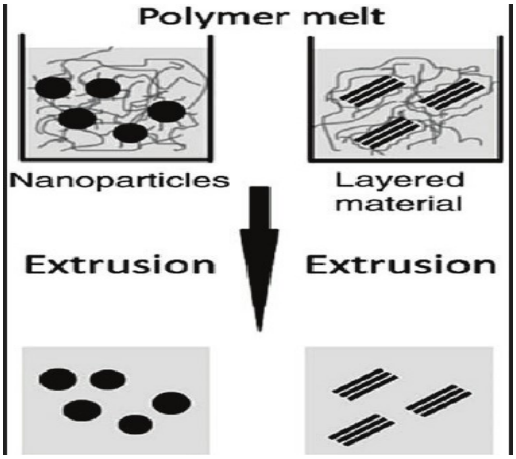

Figure 6: Preparation of nanocomposites using Melt blending

Polysaccharides

Polysaccharides are important substances in the creation of textile materials because they can be employed as fiber, coating, or stabilizing components. They are renewable resources that have received a great deal of attention due to their biocom-

patibility, biodegradability, and wide range of biological activity (e.g., anti-inflammatory, immunoregulation, anticancer, anticoagulant, antioxidant, antibacterial, and hypoglycemic action). As a result, they have seen widespread use in materials engineering, specifically in packaging systems, tissue engineering, controlled medication delivery, flexible electronics, and 3D printing. They are natural macromolecules made up of monosaccharide units joined together covalently by glycosidic bonds to create polymer chains[36-40]. Today, thousands of polysaccharides can be extracted from natural sources, including plants (e.g., cellulose, starch, and pectin), algae (e.g., alginate, agar, fucoidan, and carrageenan), animals (e.g., hyaluronic acid, heparin, chitin, and chitosan), and microorganisms (e.g., xanthan gum, dextran, pullulan, and bacterial cellulose)see **Figure 7**[41-44].

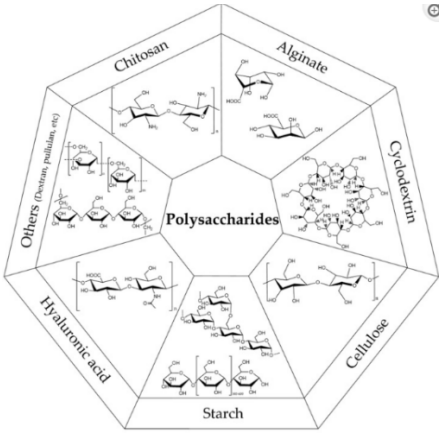

Figure 7: Chemical structures of polysaccharides commonly used in textile applications

Hybrid textiles, which contain both organic and inorganic ingredients, are a new and promising section of the textile business. Hybrid textiles may have a synergistic impact between their ingredients, enhancing their range of qualities and activity and so improving the end goods. There are numerous combinations that could result in several unique textiles with unpaired features. When paired with various MNPs, polysaccharides present a number of opportunities. In the recent decade, there has been a surge in interest in the use of polysaccharide derivatives and their nanosystems to create hybrid materials. Novel and better functionalizations enable the research and development of hitherto unattainable areas of application see **Figure 8**[45, 46].

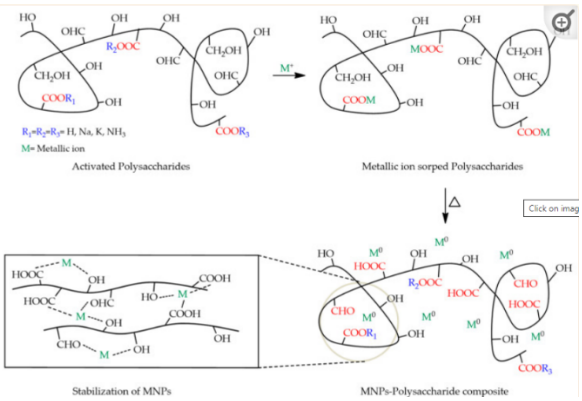

Figure 8: Representation of polysaccharides acting as reducers and stabilizers of metal nanoparticles.

Table 1: Summary of common methods for synthesis of polymer nanocomposites

Technique	Suitable filler	Suitable matrix	Solvent	Controlling factors
Ultrasonication assisted solution mixing	All types	Liquid or viscous monomers or oligomers of thermosets	Required	Sonication power and time
Shear mixing	Nanosheets	Liquid or viscous monomers or oligomers of thermosets	Required	Shapes of the rotor blades, rotating speed and time
Three roll milling	Nanosheets and nanotubes	Liquid or viscous monomers or oligomers of thermosets	Not required	Speed of roller, gap between adjacent roller
Ball milling	All types	Liquid or solid thermoplastics and thermosets	Not required	Time of milling, ball size, rotating speed, ball/nanofiller ratio
Double-screw extrusion	All types	Solid thermoplastics	Not required	Processing temperature, screw configuration, rotation speed
In situ synthesis	All types	Liquid or viscous monomers or oligomers of thermosets	Required	Chemical reaction conditions, temperature, condensation rate

Polymer Nanocomposites

Chitosan

Chitin is a natural polymer found in the exoskeletons of arthropods, arachnids, and crustaceans, as well as the endoskeletons of cephalopods such as squid and octopus. It is the second most common polysaccharide following cellulose in nature [47, 48]. It is also a required component of the cell walls of several mushrooms, and certain fungus species have been used in the industrial production of chitin. Chitosan is a valuable biopolymer composed primarily of N-deacetylated chitin produced via chemical or enzymatic deacetylation of chitin as showen in **Figure 9** .

Chitin and chitosan are both heteropolysaccharides made up of randomly distributed 2-acetamido-2-deoxy-b-D-glucose (N-acetyl-D-glucosamine) and 2-deoxy-b-D-glucopyr-anose (D-glucosamine) polymers linked together by b-(1/4) glycosidic linkages[49-51]. Because of the presence of amine groups (deacetylated functionalities), chitosan is soluble under certain conditions. Chitosan is only soluble in acidic solvents with a pH lower than its pKa (6.2-6.5). It has tremendous potential in a range of scientific domains, including biomedical, food, agriculture, cosmetics, textiles, pharmaceuticals, and other industries, thanks to its nontoxic, biodegradable, biocompatible, and microbe-resistant qualities[52, 53].

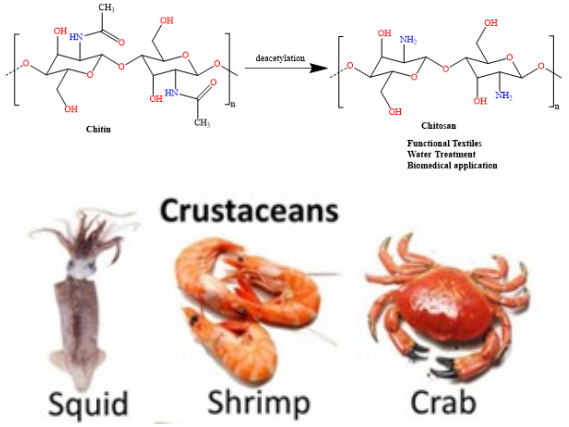

Figure 9: Chitosan chain from resources to final applications

Chitosan as an auxiliary agent in dyeing and printing processes

CS has been frequently employed as a bio-agent in textile dyeing and printing processes using synthetic and natural dyes.Its use has several advantages over traditional dyeing procedures in salt-free dyeing, including the elimination of hazardous and dangerous salts, maximal fixing and minimum hydrolysis of dyes, and a low volume of water required during the wash off process, resulting in significant cost savings[54-63].

Because CS includes a high percentage of amino groups, it provides more dye sites for anionic (reactive, acid, and direct) dyes to be absorbed by textile fibers and textiles via van der Waals forces and electrostatic attraction. As a result, CS treatment can increase the tinctorial qualities of textiles in salt-free dyeing baths, such as anionic dye affinity, color strength, and fastness[64-66].

Mohamed, F.A., M.M. Reda, and H. Ibrahim, using chitosan nanoparticles for treating cotton and viscose fabrics for enhancement of dyeing and antimicrobial properties. The dyeability of treated fabrics rose and was not affected by dye concentration, and treated cotton and viscose fabrics with various concentrations of chitosan impart a high antibacterial action with high growth suppression and treated fabrics have a higher K/S [67].

Costa, E.M., et al., worked on dyeing cotton treated with chitosan nanopartical dyed wih Navy blue everzol (a reactive dye) for enchancing color uptake and antibacterial. treated dyed cotton with navy blue everzol NTDs were shown significant antibacterial activity against MRSA, MSSA, and A. baumannii. These findings demonstrate the successful development of an easy, environmentally friendly process that allows cotton to be dyed and functionalized in one step and used in future biomedical textiles[68].

Christine Wong and Jude Clapper using Chitosan and TPP crosslink creates a nanoparticle to encapsulate dye particles using dilutions of the 0.5M solution yielded indigo dye solutions with concentrations of 0.1M, 0.2M, 0.3M, and 0.4M.

The findings show that a potentially better dye alternative can be created by being encapsulated in chitosan-TPP crosslinked nanoparticles[69].

Abdelslam, S., et al., using chitosan and chitosan nanoparticles for printing natural fabrics with natural dyes. By treating natural fabrics in three ways: pretreatment, concurrent treatment, and post-treatment with chitosan and Chitosa nanoparticlesas with different concentration then printed with extracted natural dye (turmeric, madder, or berberine) silk screen printing technique.

Natural fiber qualities improved like K/S values of treated fibers were greater and had better fastness qualities than untreated fibers.When compared to bulk chitosan, nanochitosan shown superior qualities due to its larger surface area and smaller size, and all treated materials have good fastness values for washing, perspiration, indicating greater UV protection and rubbing. [70].

Hebeish, A., et al., using natural dye loaded chitosan nanoparticles for textile printing using flat-screen printing technique. Increased dye to chitosan nanoparticle ratio leads in greater K/S values of the printed cloth independent of fixation procedure[71].

Multi-functional textile finishing with chitosan

Surface modification of fabrics with CS is used to create highly active textile surfaces with a variety of functionalities, including antimicrobial and antiviral activities, deodorizing, flame retardancy, antistatic, shrink-resistance, water repellency, and UV protection. There are actually two main ways to use CS in surface modification formulations: as an active agent imparting the desired characteristic to the fabric and, on the other hand, as a compound supporting the efficiency of active agent release (microencapsulation) or acting as a carrier or binder material.

Antimicrobial finishing

CS is a broad-spectrum biocide (it kills germs) and biostatic (it prevents microbe growth) with strong antimicrobial activity against gram-positive and gram-negative bacteria, as well as fungi and yeasts. The key factors that greatly influence the antibacterial efficiency of CS are its positive charge, degree of N-deacetylation, mean polymerization degree, and the nature of chemical changes. Similarly, CS used as an antibacterial agent in textiles has gained popularity due to its antibacterial activity combined with good moisture retention[62, 72-77].

As an antibacterial agent, CS can operate in two ways: passively by causing a reduction in protein adsorption on bacterium surfaces, so limiting pathogen adhesion capacity (in this scenario, bacteria are not killed, but merely rejected), or actively by killing bacteria on contact.99 CS postulated the following pathways for antibacterial activity[78]:

- the polycationic structure of CS, which can be expected to interact with primarily anionic components (lipopolysaccharides (LPSs) and proteins on the microbe surface), leading in alterations in permeability, which cause cell death by causing intracellular component leakage;
- The CS on the cell's surface can form a polymer membrane, preventing nutrients from entering the cell.
- Lower MW CS enters the cell, binds to DNA, and inhibits RNA and protein production.
- Because CS can adsorb and flocculate electronegative chemicals in the cell, it disrupts the physiological functions of the microbe, resulting in cell death.

Sevil ERDOĞAN [79] using chitosan from (shrimp or crayfish) and nano-Ag mixture for finishing white cotton calico fabric against Escherichia coli. By preparing chitosan and nano-Ag solutions and treating fabric by pad-dry method with 100% squeezing pressure then the fabrics were dried at 105–110 °C and finally fixed at 120℃.

Chitosan created a colorless layer and a matrix that allowed the uniform deposition of nano-Ag particles on the fabric's surface.Additionally, the technique for coating fabrics is helpful and suitable to long lengths. Because of its affordability and ease of use, it can be used in the sector.By lowering the use of antibiotics, chitosan nano-Ag coating as a finishing helps to safeguard human health. The assessment of crayfish and shrimp wastes as chitosan is another way that environmental conservation is aided.

Silva, I.O., et al., using Chitosan/Gold Nanoparticles Coatings for Biomedical Textiles. They treated soybean knitted fabric with Chitosan/Gold Nanoparticles at 70℃ for 30min then dried at 70 ◦C for 1 h.

The incorporation of AuNPs into a chitosan matrix shown outstanding antibacterial activities against both Gram-positive and Gram-negative bacteria, UV-light protection (UPF + 50), and washing fastness up to five laundry cycles. Aside from their high potential for biomedical applications, the coated AuNPs/chitosan soybean-based fibres demonstrated better thermal stability and intriguing properties for textile structural coloration[80].

Korica, M., et al. using chitosan Nanoparticles for enhancing antibacterial of viscose fabric by impesing viscose samples into the NCS or NCS + Zn dispersion for 30 min, at room temperature then squeezing.

The antibacterial activity of viscose fabrics functionalized with chitosan nanoparticles (without and with embedded zinc ions) were improved by successful irreversible binding of antibacterial agents using two different viscose fabric pretreatments: TEMPO oxidation and TOCN coating, which provided carboxyl and aldehyde groups onto/into the viscose fabric[81].

Mohamed, F., M. Reda, and H. Ibrahim, using chitosan nanoparticals for cotton fabric for enhancing easy care and antibacterial by using -dry -cure technique.

Even after 10 washes, the resulting materials exhibit anti-crease and easy-care qualities, as well as antibacterial capabilities. After the multifinishing procedure, the materials retain a significant amount of their strength and comfort. Finally, our newly prepared freeze drying chitosan nanoparticles advance textile finishing processes by introducing ease and care characteristics, antibacterial properties, and fabric comfort that are primarily recommended for use in heavy-duty industrial fabrics and medical applications[67].

Antiviral functionalization

Previous studies have indicated that marine polysaccharides like CS have antiviral action.CS exhibits antiviral action against human viruses such as

H1N1 influenza A, CMV strain AD, and SARS-CoV-2, according to several investigations[82-84].

Mori Y, Ono T, Miyahira Y, et al. using silver nanoparticle/chitosan composites against H1N1 influenza A virus. The composites' antiviral activity was assessed by the lowered TCID50 ratio of viral suspensions after treatment with the composites. The antiviral activity of the AgNP/Ch composites increased with the number of Ag NPs tested for all sizes of Ag NPs examined. For equivalent quantities of Ag NPs, composites comprising smaller Ag NPs demonstrated stronger antiviral efficacy[85].

Application in Medical Textiles

Textiles are presently used in a wide range of industries and applications. The medical industry is one of them. Medical, hygiene, and health are important and expanding segments of the textile industry. Medical textiles are one of the most important, constantly growing, and ever-expanding topics in technical textiles. Medical textiles are constructs that have been designed and built for medical purposes. The uses range from a single thread stitch to complicated composite structures for bone replacement, and from a simple cleaning wipe to specialized barrier textiles used in operating rooms. Textile materials and products designed to meet certain characteristics are suited for any medical and surgical application requiring a combination of strength, flexibility, and, in some situations, moisture and air permeability[21, 75, 86, 87].

Table 2: Application of polymer nano composites in protective textiles

Polymer	**Nanoparticles**	**Synthesis of polymer nanocomposites**	**substrate**	**Application Technique**	**Properties**	**Ref**
Chitosan	Graphene nanosheet	Blending	Cotton	pad-dry-cure	UV-protection	[18]
Chitosan	titanium dioxide and/or zirconium oxide	Blending	Cotton	Coating technique	UV-protection-Antibacterial activity	[88]
Chitosan/clay	Silver	In situ growth of nanoparticles in polymer matrix	Cotton	pad-dry-cure	Flame retardant-Antibacterial activity- UV-protection	[89]
Chitosan grafted-Polyvinyl acetate	TiO2 and ZnO /TiO2 nanoparticles	Blending	Cotton	pad-dry-cure	Water repellent-UV Protection-Antibacterial Activity-Self -cleaning	[90]
Chitosan	CuO	Double in situ method	cotton and cotton/polyester	pad-dry-cure	Antibacterial activity	[91]
Chitosan	ZnO	Double in situ method	Cotton	pad-dry-cure	Antimicrobial and UV Protection	[92]

Table 3: Textile materials functionalized with chitosan and metal nanoparticles. Polysaccharide function towards MNPs.

Polysaccharide Function	NPs (Shape, Size)	Textile Substrate, Structure	Application Method	Properties	Ref
Antimicrobial activity	Ag (n.d. *)	Cotton, woven	Packaging	Antimicrobial activity against S. aureus, P. aeruginosa, C. albicans, and A. niger; chitosan increased air permeability and water absorbance	[93]
	Ag (n.d.)	Cotton, woven	Medical and UV-protective textiles	Air and water permeability decreased, whereas tensile strength and elongation increased; superior UV blocking; antimicrobial activity against P. aeruginosa, S. aureus, A. niger, and C. albicans	[94]
	Ag (spherical, <100 nm)	Cotton, woven	Hygienic products	Antibacterial activity against S. aureus improved with the addition of AgNPs	[95]
	Chitosan-TiO_2 and chitosan-TiO_2/ZnO	Cotton, woven	Antimicrobial, self-cleaning, and UV-	Enhanced antibacterial activity against S. aureus, E. coli, and A. niger; improved self-cleaning and	[90]

	(spherical, 11.7 nm)		protective textiles	UV-protective properties	
	Ag (n.d.)	PET, nonwoven	Antimicrobial textiles (wound dressings)	Improved antibacterial activity against E. coli and S. aureus	[96]
	Psidium guajava extract-ZnO (spherical, 12–18 nm and 5–7 nm (water and ethanol extract)	Cotton, woven	Antimicrobial textiles	Composite with ZnONPs had better antimicrobial activity and UV protection in the presence of chitosan	[97]
	PVP-Ag (n.d., 30 nm)	Acrylic acid and chitosan-grafted polypropylene, nonwoven	Antimicrobial textiles	Antibacterial resistance increased after coating with chitosan and improved further with the addition of AgNPs (E. coli, S. aureus, and B. subtilis)	[98]
Antimicrobial activity; immobilization	Ag (n.d., 40–70 nm)	PET (n.d.)	Antimicrobial and flame-retardant textiles	Good antibacterial resistance against E. coli; flame retardance was improved with the addition of AgNPs along with chitosan	[99]
	Chitosan-Ag (spherical, 20 nm)	Cotton, woven	Antibacterial, UV-protective, and flame-retardant textiles	Antimicrobial activity against E. coli, S. aureus, and C. albicans; small reduction after 20 washing cycles; improvement in UV-protective and flame-retardant properties	[89]
	CMCh-Ag (spherical, 10–20 nm)	Viscose, woven	Antimicrobial textiles (wound dressings)	Superior antibacterial activity against S. aureus compared to that against E. coli with increasing concentration of AgNPs	[100]
	Ag (n.d., 34.4 nm)	Cotton, woven	Antibacterial textiles	No cytotoxic effect on human skin; excellent antibacterial durability against E. coli and S. aureus achieved by a small Ag dosage	[101]
	nO and TiO_2 (rod-shaped, 18 nm)	Cotton, woven	Antimicrobial and UV-protective textiles	The durability of antibacterial efficiency against K. pneumonia and S. aureus increased up to 10 washing cycles the using sol–gel method	[102]
Antimicrobial activity; stabilizing agent	Chitosan-Cu (n.d., 20–30 nm)	Cotton and cotton/polyester, woven	Antimicrobial textiles	Antibacterial effect was predominantly observed against S. aureus in comparison with E. coli	[103]
Antimicrobial activity; substrate	Carboxymethyl pullulan-ZnO (spherical, 9 nm)	Cotton, woven	pH, thermosensitive, and antibacterial agents	Antimicrobial activity towards S. aureus and E. coli; textile sensitive to temperature between 24 and 40 °C and pH 3, 7, and 10	[104]
	Ag (n.d.)	Cotton, woven	Antimicrobial textiles	Improved antimicrobial properties against E. coli and B. subtilis	[105]
	Ginger oil-Ag (spherical, 14 nm)	Cotton, woven	Wound patches/gauzes	Gauzes with antimicrobial activity against C. albicans, E. coli, and S. aureus; improved UV protection; brilliant yellow-brownish color	[106]
	Ag (n.d.)	Cotton, woven	Antimicrobial textiles, wound dressings	Good antibacterial activity against S. aureus and E. coli	[107]
	Tamarin-Ag (n.d., 20–50 nm)	Linen, woven	Antibacterial, UV-protective, and flame-retardant textiles	Antibacterial activity against S. aureus and E. coli; UV protection and improved antioxidant activity; moderate improvement of flame retardance	[108]
	Fe, Cu, Ag, Co, and Ni (n.d.)	Cotton, woven	Catalyst strips	High catalytic efficiency for the conversion of toxic substances from azo dyes and nitrophenols	[109]

	Co (n.d., 90 ± 22 nm)	Cotton, woven	Catalyst for the reduction of pollutants in water	CoNPs showed reduction of congo red dye (96% of the dye was degraded in only 21 min) and nitrophenols in aqueous solutions	[110]
Immobilization	Cu (n.d., 80–90 nm)	Cotton, woven	Catalyst for dye reduction	Cu catalyst remained active even after three usages; excellent stability and recyclability during the degradation process	[111]
	ZnO and Ag (n.d., 35 and 40 nm)	Cotton, woven	Technical textiles with antimicrobial and UV protection properties	Antimicrobial action against S. aureus and E. coli; noticeable increase in UV blocking and in bending rigidity; functional properties maintained even after 15 washing cycles	[112]
	ZnO and TiO_2 (n.d., 10–30 nm) and silicon dioxide (SiO_2) (n.d., 10–20 nm)	Cotton/polyester, woven	Antibacterial and UV-protective textiles	Good antibacterial effect for fabrics coated with TiO_2, followed by ZnO and SiO_2; higher UPF for the samples with TiO_2, followed by ZnO, SiO_2NPs, and chitosan	[113]
	Fe $(NO_3)_3$ (n.d)	Ramie, woven	Flame-retardant textiles	Flame-retardant properties were improved; mechanical properties were reduced	[114]
	Chitosan-Ag (spherical, n.d.)	Polyamide, woven	Antimicrobial textiles	Bacterial activity with the addition of AgNPs but reduced after 20 washing cycles; consistent color, even after one year	[115]

Alginate

Alginates are natural anionic polysaccharides that can be isolated from a variety of brown sea algae and bacteria, including Pseudomonas and Azotobacter. Alginate polymers are made up of two monomers, D-mannuronic acid (M blocks) and L-guluronic acid (G blocks), which are connected together by -(1,4) (M residue) and -(1,4) (L residue) glycosidic linkages, resulting in a copolymer with varying types of blocks (MM, GG, or GM) depending on the extraction source[21, 87, 116-124].

AgNPs can be mixed with alginate to be utilized as a coating/finishing agent in fabrics, or they can be integrated directly into the alginate fiber during wet or electrospinning processes. Zhao et al., for example, described the wet spinning of alginate fibers embedded with AgNPs, demonstrating that the antibacterial activity was efficient against both E. coli and S. aureus and had a high cell-killing efficiency in human cervical cancer (HeLa) cells[125].

Starch

Because of its promising physicochemical qualities, including as biocompatibility, biodegradability, non-toxicity, and cohesive film-forming properties, starch is a natural polymer of special interest for a wide range of industrial applications. One of the least expensive polysaccharides is this sustainable biopolymer. It is widely available and may be derived from various plant parts such as stalks, roots, and seeds, with cassava, wheat, rice, corn, and potatoes being the primary sources. Starch is a semi-crystalline polymer of anhydroglucose units linked by -(1,4)-glycosidic linkages, made up of two monomers: amylose and amylopectin. Amylose, which is composed of a linear glucose chain, is responsible for the amorphous structure of starch granules and accounts for 15-30% of their makeup. In contrast, amylopectin is a branched glucose chain with crystalline zones and represents 70–85% of the starch[116, 126-130].

Table 4: Viscose Fabric Functionalized with Copper and Copper Alginate Treatment Toward Antibacterial and UV Blocking Properties.

Polysaccharide Function	NPs (Shape, Size)	Textile Substrate, Structure	Application	Results	Ref
Reducing agent; substrate	Ag (n.d.)	Alginate, electrospun fibers	Sensors	Sensitive humidity sensor for breathing monitorization (humidity range between 20% and 85%)	[37]
Reducing agent; substrate	Polypyrrole/Ag (n.d.)	Alginate, non-woven	Multifunctional textiles	Highly conductive, hydrophobic, and UV-resistant fabric; antistatic properties improved; thermally stable	[131]

Stabilizing agent; immobilization	Ag (spherical, 10–25 nm)	Alginate, wet-spun fibers	Antibacterial textiles	Excellent antibacterial activity against E. coli and S. aureus; cytotoxic effects against cancer HeLa cells	[132]
Substrate	Ag (n.d.)	Chitosan/PET/alginate, LBL composite	Nano/ultrafiltration membranes	Antibacterial activity against E. coli and S. aureus; remotion of oils up to 93%; NP retention greater than 98%	[133]

Table 5: Textile materials functionalized with starch and metal nanoparticles. Polysaccharide function towards MNPs.

Polysaccharide Function	NPs (Shape, Size)	Textile Substrate, Structure	Application	Results	**Ref.**
Immobilization	ZnO (flakes and nanoflowers, 16.2 nm)	Cotton, woven	Antibacterial textile	ZnO/cotton–starch (3%) with bacterial reduction of 96% (S. aureus) and 76% (E. coli)	**[134]**
	ZnO (spherical, 52.42 nm); ZnO on fabric (hexagonal, 11.96 nm)	Polyester, woven	Multifunctional textiles (flame-retardant, self-cleaning, antimicrobia	Flame-retardant with no dripping; hydrophobic with self-cleaning properties (ΔRGB of 73.9); cell viability of 129%; bacteria reduction of 97%, 100%, and 94% (E. coli, S. aureus, and C. albicans, respectively)	**[134]**
Reducing agent	CuO (spherical, 10–100 nm)	Cotton,woven	Antimicrobial textiles (medical,cosmetic, sports)	Hydrophobicity (WCA of 110°); antimicrobial activity of 96%, 94%, 92%, and 89% (against S. aureus, E. coli, P. fuorescens, B. subtilis, and C. albicans, respectively); washing durability	**[135]**
	MnO_2 (n.d.)	Cotton, woven	Agriculture, medical textile, water treatment	Superabsorbent (227%); photocatalytic (ΔRGB of 75); good antimicrobial properties for the hydrogel but very low for the fabric treated with the hydrogel (poor adhesion)	**[136]**
Reducing and stabilizing agent	Ag (n.d., 25.7 nm)	Cotton, knit	Medical textiles, water purification	Antibacterial activity against S. aureus and E. coli (halo)	**[137]**
Stabilizing agent	ZnO (spherical, 88 nm)	Cotton, woven	Antibacterial textiles	Hydrophobicity (WCA of 95.5°); antimicrobial activity with a zone of inhibition of 1 mm (E. coli); washing durability	**[138]**
	ZnO (n.d.)	Face masks, non-woven	Face masks	Antimicrobial activity of the ZnONPs with a zone of inhibition of 3.67 and 2.33 mm (S. aureus and E. coli, respectively)	[132]

Cyclodextrins

CDs are cyclic oligosaccharides formed by the enzymatic breakdown of starch and consist of six, seven, or eight -(1, 4)-linked -D-glucopyranose units. Their structure is a truncated circular cone with a hydrophobic interior cavity and a hydrophilic outside surface. Inclusion complexes can develop in the hydrophobic inner cavity with guest molecules, which are held together by Van der Waals and hydrophobic forces. Because of their ease of manufacture, availability, cavity diameter, and low cost, -CDs are the most often used CDs in the textile sector. Dyeing auxiliary to increase dye adsorption and K/S; encapsulation of active chemicals such as fragrances, medicines, and antimicrobial agents; and fiber spinning are some of their applications[129, 139-141].

According to Keshavarz et al., an antibacterial and drug-delivery fabric was created by in situ synthesis of polyamidoamine (PAMAM)/-CDs/Ag nanocomposites on a polyester fabric. PAMAM enabled polyester fabric aminolysis, resulting in stable connections with -CDs/Ag composites. The ensuing nanocomposite fabric demonstrated a 45% drug release of the molecules placed into the -CDs cavities after 150 h and a 100%, 100%, and 99% microbial decrease in E. coli, S. aureus, and C. albicans, respectively[142]. Another study used AgNPs to build an antimicrobial drug-delivery system by synthesizing them on a -CD/ketoconazole (KZ) combination and then loading them onto cotton fabric. Ketoconazole is an antifungal medication, and the addition of AgNPs to -CDs/KZ increased its antibacterial capabilities while also controlling its release rate. Microbial decrease was 100% in C.

albicans and A. niger and around 85% in E. coli and S. aureus in the sample prepared with 2% Ag[143]. Antimicrobial cotton fabrics were created by utilizing -CDs and sulfated -CDs (S--CDs) to host AgNP inclusion complexes. The most advantageous technique was determined to be the treatment with the derivative -CDs-AgNP complex and crosslinking with ethylenediaminetetraacetic acid (EDTA). S--CDs + AgNPs + EDTA inhibited S. aureus by 95% and 79% (before and after 10 washing cycles, respectively) and E. coli by 95% and 77% (before and after 10 washing cycles, respectively)[144].

Table 6: Textile materials functionalized with cyclodextrins and metal nanoparticles. Polysaccharide function towards MNPs.

Polysaccharide Function	NPs (Shape, Size)	Textile Substrate, Structure	Application	Results	Ref.
Reducing and stabilizing agent	Ag/TiO_2/β-CDs (semi-spherical, 48 nm)	Cotton, woven	Antibacterial textile, self-cleaning, environmental remediation	Ag/TiO_2/β-CDs samples with excellent self-cleaning properties (methylene blue); antibacterial activity against S. aureus of 96.8%	[145]
	Ag (n.d. *)	PET, non-woven	Wound dressing, antibacterial, drug release	Poly-CDs: Ag adsorption of 450 μg·cm^{-2} (24 h), Ag release of 23 μg·cm^{-2} (3 days), bacterial reduction of 4 log10 (S. aureus) and 6 log10 (E. coli); PEM coating: reduced Ag diffusion (8.0 μg·cm^{-2}), bacterial reduction of 3 log10 (S. aureus) and 5 log10 (E. coli)	[96]
	Ag (n.d.)	PET, non-woven	Wound dressing, antibacterial, and antalgic drug release	PEM system allowed for complete IBU-L release in 6 h; PET-CD-Ag-PEM had a bacterial reduction of 4 log10 against S. aureus and E. coli; cell viability of 0%	[146]
Stabilizing agent; immobilization	Ag_2O (n.d., 20.6 nm); Ag/β-CDs (n.d., 9.5 nm)	Polyester, woven	Drug release and antimicrobial textile	Drug release of 45% (150 h); microbial reduction in E. coli, S. aureus, and C. albicans of 100%, 100%, and 99%, respectively	[142]
	Ag (cubic, 31 nm)	Cotton, woven	Antibacterial textile	S-β-CDs + AgNPs + EDTA with a bacterial reduction in S. aureus of 95% and 79% and in E. coli of 95% and 77% (before and after 10 washing cycles, respectively)	[144]
	Ag (n.d.)	POM/β-CD electrospun microfiber mat	Waste treatment, molecular recognition, catalysis	Ag/POM/β-CDs mats (average fiber diameter of 6.4 μm) with excellent catalytic degradation of organic dyes in the presence of $NaBH_4$	[147]

Table 7: Some of the recent nanopolymers–biopolymers coating combinations reported in the scientific literature and their specific properties

NPs	Used polymer	The effect of nanoparticles addition	Ref
Zinc oxide nanorods	Gelatin/clove essential oil	Enhancement of antimicrobial activity	[148]
Zinc oxide nanorods	Soybean polysaccharide	Enhancement of antimicrobial activity: E. coli (from 7 to 5 log after 12 h) and S. aureus (from 6 to 1 log after 12 h)	[149]
PVA/graphene oxide/ starch silver	PVA	Antibacterial properties	[150]
Zinc oxide nanopartiles Copper oxide	Carrageenan	ZnO NPs strongly improved antimicrobial activity against E. coli and L. monocytogenes	[151]
Zinc oxide nanorod nanokaolin	Semolina	Enhancement of UV barrier properties and antimicrobial activity against E. coli (from 0 to 3 mm)	[152]
Rice cellulose nanocrystals	CHTS/PVA	Without changes in antifungal response C. gloeosporioides and L. theobromae and antimicrobial against S. mutans, S. aureus, E. coli, and P. aeruginosa activities	[153, 154]
Copper oxide nanocomposites	CHTS	Enhancement of antimicrobial activity against E. coli, P. aeruginosa, S. aureus, B. cereus (all results were depending on the concentration and ratio of MMT and CuONPs	[148]
Flax cellulose nanocrystals	CHTS	Enhancement of antimicrobial activity: P. aeruginosa, E. faecalis, L. monocytogenes, E. coli, and S. aureus (from 6.31 to 16.05 mm of inhibition zone)	[155]
Nanocrystals and silver nanoparticles	CHTS	Enhancement of antimicrobial and antifungal activity (from 0 to 96 mm2 of inhibition zone depending on the concentration and ratio of silver nanoparticles and BCNC)	[156]
CHTS NPs	Tara gum	Antimicrobial activity against E. coli (from 0 to 87.32 mm2 of inhibition zone) and S. aureus (from 0 to 111.71 mm^2)	[157]
CHTS/gallic acid NPs	Konjac glucomannan	Enhancement of antimicrobial activity: S. aureus (from 0 to 20 mm of inhibition zone) and E. coli (from 0 to 12 mm)	[158]
Potatoes starch Tapioca starch CHTS	Turmeric nanofibres	Antimicrobial activity: B. cereus, E. coli, S. aureus, and S. typhimurium (the values were depending on the type of biopolymer)	[159]
Halloysite nanotubes Zinc oxide nanoparticles	alginate	Enhancement in antimicrobial activity against E. coli (from 7 to 0 log after 3 h) and L. monocytogenes (from 6 to 0 after 9 h)	[159]

Cellulose

Cellulose is a fibrous natural polymer with nanoscale dimensions, hence the name nanocellulose. Nanocellulose is a polysaccharide composed of -(1-4) linked anhydro-D-glucose units with a polymerization degree of up to 20,000, depending on the cellulose source. Plants, bacteria, algae, and mammals are all natural sources of nanocellulose. There are three varieties of nanocellulose: cellulose nanocrystals (CNCs), cellulose nanofibrils (CNFs), and bacterial nanocellulose (BNC). CNCs with needle-like or rod-like morphologies are produced by chemical hydrolysis of pure or delignified cellulose sourced from plants. Strong acids hydrolyze the disordered or amorphous areas of cellulose, leaving the crystalline regions intact because they are resistant to acid digestion[160-162]. The chemical, physical, and biological features of nanocellulose-based materials are particularly fascinating. Because of its nanosized structure, its inertness and increased surface area influence the availability of hydroxyl groups, allowing the adsorption of various ions, atoms, and molecules. Aside from being physically strong, nanocellulose has morphological, chemical, and optical qualities that can be adjusted. Furthermore, it is a plentiful and renewable resource with a low production cost[163]. Cellulose, in various forms, is frequently used in textile finishing as a reducing or stabilizing agent, binder, and stiffener to aid in the incorporation of MNPs into the fabric, embedding characteristics into the final product. [19, 164-173]

Other Polysaccharides

Pectin is a widely distributed polysaccharide that is mostly formed of -(1,4)-linked galacturonic acid homopolymer and is one of the most complicated anionic heteropolysaccharides. It is easily available because it is a component of plant cell walls. Pectin has so emerged as a viable biopolymer, owing to its sustainability, biocompatibility, and biodegradability. It is feasible to obtain electrospun fibers made entirely of pectin; however, this is a difficult and time-consuming technique. As a result, pectin is commonly employed in a composite blend of electrospun functional composite fabrics. Hyaluronic acid is made up of numerous glucuronic acid and N-acetyl-glucosamine repeats. It is abundant in nature and found in all mammalian species, but it has also been found in Pseudomonas bacteria and other creatures[174-181]. Hyaluronic acid is made up of numerous glucuronic acid and N-acetyl-glucosamine repeats.

Table 8: Textile materials functionalized with cellulose and MNPs. Polysaccharide function towards MNPs.

Polysaccharide Function (Cellulose Type)	NPs (Shape, Size)	Textile Substrate, Structure	Application	Results	Ref.
Immobilization (CNFs)	Ag-NH_2 (spherical, ~20 nm)	CNFs and gelatin, non-woven	Wound dressing	Improved mechanical, self-recovery, and hemostatic (gelation) properties; antibacterial properties against S. aureus and P. aeruginosa; fluid balance on the wound bed	[182]
	Ag (n.d. *)	Cotton, woven	Disposable e-textiles (electronic devices integrated into fabrics)	Better surface wetting and improved inkjet printing process; higher-speed inkjet printing	[183]
	ZnO (n.d., 90 ± 10 nm)	Cotton, woven	UV-protective textiles	Reduced the agglomeration of ZnO; decreased air permeability; improved mechanical properties; showed a bacteriostatic inhibition effect against E. coli and S. aureus	[184]
Immobilization (viscose)	TiO_2 (n.d., 50 nm)	Cotton	n.d.	Photocatalytic self-cleaning and permanently stiff cotton properties; increased degradation rate of orange II dye under UV–vis light irradiation	[185, 186]
Reducing and stabilizing agent (Na-CMC)	Ag (spherical, 2–8 nm, 5–35 nm; whiskers, L: 130–420 nm, W: 15–40 nm)	Cotton, woven	Antibacterial textiles	Bactericidal activity against bacterium S. epidermidis and fungus C. albicans	[186]

It is abundant in nature and found in all mammalian species, but it has also been found in Pseudomonas bacteria and other creatures. Hyaluronic acid is extremely hydrophilic and water soluble. It has unusual rheological properties, such as considerable water retention, and is commonly classified as a lubricant [145,146]. Hyaluronic acid is a promising option for functional medicinal materials that enhance wound healing due to its ubiquitous presence in the mammalian extracellular matrix. It was claimed that electrospun non-woven medicinal fabrics contained hyaluronic acid and AgNPs in their formulation. Hyaluronic acid was used in these fabrics to stimulate tissue regeneration and prevent cell adhesion. Despite the fact that hyaluronic acid is extremely soluble, its release from textiles has been described as sluggish, taking 1.5 to 2.5 days to release 50%. In tendon and peritendinous regions, these textiles reduced inflammation, increased collagen deposition, and inhibited cell adhesion.[187, 188].

Carrageenans are polysaccharides derived from Rhodophyta marine algae that are made up of alternating 3-linked and 4-linked -D-galactopyranose. Carrageenans, which are constituted of galactomannans, have a mechanical synergy with locust bean gum, which is produced from the seeds of the carob tree. Carrageenans and locust bean gum are both well-known gelling agents. They are also widely available, sustainable, and biocompatible. Because of their biocompatibility, biodegradability, and, in certain cases, immunoregulatory function, these polymers are primarily envisioned for textile medical applications like as wound dressings and indwelling devices. When employing these polymers, AgNPs are employed as an antibacterial agent to control and prevent infections in the great majority of applications[19, 189].

Table 9: Textile materials functionalized with other polysaccharides and metal nanoparticles. Polysaccharide function towards MNPs.

Polysaccharide Function	NPs (Shape, Size)	Textile Substrate, Structure	Application	Results	Ref.
Antimicrobial activity (Dextran)	Ag (spherical, 8–58 nm)	Cotton, n.d. *	Wound dressing	Formulations exhibited moderate antimicrobial activity against A. niger, C. albicans, S. aureus, and E. coli	[190]
Reducing and stabilizing agent (κ-carrageenan and locust bean gum)	Au (spherical, 21–45 nm)	n.d.	General use	κ-carrageenan and locust bean gum reduced and stabilized AuNPs; the formulation can be laminated on non-woven fabric at industrial large scale	[191]
Stabilizing agent (pectin)	Ag (n.d. *, 24 nm)	Pectin, PVA, PVP, and mafe-	Wound healing	Low antibacterial activity against S. aureus, E. coli, and P. aeruginosa;	[188]

		nide acetate, non-woven		acceptable cytotoxicity, including faster in vivo wound healing	
Stabilizing agent (pullulan)	Ag (spherical, 20 nm; in sodium silicate)	Cotton, n.d.	n.d.	Functionalized cotton water uptake became stimuli-responsive to pH and temperature between 24 and 30 °C (neutral and acid pH)	[192]
Substrate (pectin and hyaluronic acid)	Ag (spherical, 8.6 nm)	Pectin, hyaluronic acid, and PVA, non-woven	Wound dressing	High antimicrobial activity against B. subtilis, S. aureus, and E. coli; histological analysis displayed a faster healing process, attributed to the presence of hyaluronic acid	[188]
Substrate (pectin)	Ag (spherical, 3.7–8.6 nm)	Pectin, non-woven	Wound healing, catalysis, and Raman enhancement	AgNPs homogeneously distributed in the pectin nanofibers, and their size may be tailored; AgNP release took 4 weeks	[174]
Substrate (PVA, gum arabic, and polycaprolactone)	Ag (spherical, 10–100 nm)	PVA, gum arabic, and polycaprolactone, non-woven	Wound dressing	Low antimicrobial activity against S. aureus, E. coli, P. aeruginosa, and C. albicans. Improved adequacy of water-vapor permeability and porosity for wound-dressing use; suitable cytotoxicity	[193]

Conclusion

The application of polysaccharides is critical in the development of functional, eclectic, and environmentally friendly fabrics utilizing MNPs. The combination of biopolymer (Polysaccharides) and MNPs has significantly expanded the area of textile functionalization, encouraging the development of novel functions, stacking properties, and their augmentation through synergy or increased efficacy. The capacity of biopolymer to decrease and stabilize MNPs in fabrics has significantly enhanced their activity, concentration, and washing fastness. Reduced MNP concentration (without sacrificing activity) and greater washing fastness indicate an essential role in minimizing MNP environmental pollution, which should be vigorously encouraged. Furthermore, the totally sustainable nature of polysaccharides, as well as their ability to reduce (or remove) toxic reduction chemicals, should be investigated.

Funds

The authors are grateful thank to the National Research Centre, Giza, Egypt for the financial support of this work

Conflict of Interest

The authors declared no competing interests in the publication of this article

Acknowledgment

The authors are gratefully grateful to acknowledge the Faculty of Applied Arts, Benha University. Furthermore, the authors are gratefully grateful to acknowledge the Central Labs Services (CLS) and Centre of Excellence for Innovative Textiles Technology (CEITT) in Textile Research and Technology Institute (TRTI), National Research Centre (NRC) for the facilities provided.

References

1. Salem, S.S., Hammad, E.N., Mohamed, A.A. and El-Dougdoug, W. A comprehensive review of nanomaterials: Types, synthesis, characterization, and applications, *Biointerface Research in Applied Chemistry*, **13**(1) (2022).

2. Wu, Q., Miao, W.-s., Zhang, Y.-d., Gao, H.-j. and Hui, D. Mechanical properties of nanomaterials: A review, *Nanotechnology Reviews*, **9**(1) 259-273 (2020).

3. Hassabo, A.G., Elmorsy, H.M., Gamal, N., Sedik, A., Saad, F., Hegazy, B.M. and Othman, H.A. Applications of nanotechnology in the creation of smart sportswear for enhanced sports performance: Efficiency and comfort, *Journal of Textiles, Coloration and Polymer Science*, **20**(1) 11-28 (2022).

4. Hassabo, A.G., Gamal, N., Sedik, A., Saad, F., Hegazy, B.M., Elmorsy, H.M. and Othman, H.A. Smart wearable fabric using electronic textiles – a review, *Journal of Textiles, Coloration and Polymer Science*, **20**(1) 29-39 (2022).

5. Elkodous, M.A., El-Husseiny, H.M., El-Sayyad, G.S., Hashem, A.H., Doghish, A.S., Elfadil, D., Radwan, Y., El-Zeiny, H.M., Bedair, H., Ikhdair, O.A., Hashim, H., Salama, A.M., Alshater, H., Ahmed, A.A., Elsayed, M.G., Ali, M.N.Y., Elahmady, M., Kamel, A.M., Elkodous, M.A., Maallem, I., Kaml, M.B.S., Nasser, N., Nouh, A.A., Safwat, F.M., Alshal, M.M., Ahmed, S.K., Nagib, T., El-sayed, F.M., Almahdi, M., Adla, Y., ElNashar, N.T., Hussien, A.M., Salih, A.S., Mahmoud, S.A., Magdy, S., Ahmed, D.I., Hassan, F.M.S., Edward, N.A., Milad, K.S., Halasa, S.R., Arafa, M.M., Hegazy, A., Kawamura, G., Tan,

W.K. and Matsuda, A. Recent advances in waste-recycled nanomaterials for biomedical applications: Waste-to-wealth, *Nanotechnology Reviews*, **10**(1) 1662-1739 (2021).

6. Ahmed, H.M., Roy, A., Wahab, M., Ahmed, M., Othman-Qadir, G., Elesawy, B.H., Khandaker, M.U., Islam, M.N. and Emran, T.B. Applications of nanomaterials in agrifood and pharmaceutical industry, *Journal of Nanomaterials*, **2021** 1-10 (2021).

7. Majidi, S., Sehrig, F.Z., Farkhani, S.M., Goloujeh, M.S. and Akbarzadeh, A. Current methods for synthesis of magnetic nanoparticles, *Artificial Cells, Nanomedicine, and Biotechnology*, **44**(2) 722-734 (2014).

8. Roshdy, Y.A.E.-m., El-Shamy, M.N., Mohamed, H.A., Gaafar, Z.S. and Hassabo, A.G. Self-cleaning cotton textiles enhanced with nanotechnology, *J. Text. Color. Polym. Sci.*, - (2024).

9. Mohammed, N., Nawar, S.H., Etawy, M.S., Nassar, G.E. and Hassabo, A.G. Nanotechnology and its applications in industry and product design, *J. Text. Color. Polym. Sci.*, **21**(2) 273-284 (2024).

10. Abd El-Aziz, E., El-Desoky, S.S., El-Bahrawy, G.A., Ezat, H.A., Abd El-Rahman, R., abdelraouff, A. and Hassabo, A.G. Nanotechnology to improve the performance of silk fabric, *J. Text. Color. Polym. Sci.*, **21**(1) 33-38 (2024).

11. Hassabo, A.G., Elmorsy, H., Gamal, N., Sediek, A., Saad, F., Hegazy, B.M. and Othman, H. Applications of nanotechnology in the creation of smart sportswear for enhanced sports performance: Efficiency and comfort, *J. Text. Color. Polym. Sci.*, **20**(1) 11-28 (2023).

12. Gowri, S., Khan, M.A. and Srivastava, A.K. Textile finishing using polymer nanocomposites for radiation shielding, flame retardancy and mechanical strength, *Textile & Leather Review*, **4**(3) 160-180 (2021).

13. Kandasamy, S. and Prema, R.S. Methods of synthesis of nano particles and its applications, *Journal of Chemical and Pharmaceutical Research*, **7**(3) 278-285 (2015).

14. Baig, N., Kammakakam, I. and Falath, W. Nanomaterials: A review of synthesis methods, properties, recent progress, and challenges, *Materials Advances*, **2**(6) 1821-1871 (2021).

15. HUSSAIN, F. and HOJJATI, M. Review article: Polymer-matrix nanocomposites, processing, manufacturing, and application: An overview, *Journal of Composite Materials*, **40**(17) 1511-1575 (2006).

16. Selim, M.S., Shenashen, M.A., El-Safty, S.A., Higazy, S.A., Isago, H. and Elmarakbi, A. Recent progress in marine foul-release polymeric nanocomposite coatings, *Progress in Materials Science*, **87** 1-32 (2017).

17. Caicedo, C., Melo-López, L., Cabello-Alvarado, C., Cruz-Delgado, V.J. and Orta, C.A.Á.-. Nanocomposite and biodegradable polymers applied to technical textiles, *Dyna*, **86**(211) 288-299 (2019).

18. Zayed, M., Baker, M. and Ghazal, H. Recent developments in the utilization of polymer nanocomposites in textile applications, *Journal of Textiles, Coloration and Polymer Science*, **20**(2) 147-170 (2023).

19. Ragab, M.M., Othman, H. and Hassabo, A.G. Natural polymers and their application in the textile sector (review), *J. Text. Color. Polym. Sci.*, - (2024).

20. 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).

21. Hassabo, A.G., Gouda, N.Z., Khaleed, N., Shaker, S., Abd El-Salam, N.A., Mohamed, N.A. and Abd El-Aziz, E. Natural polymers in medical textiles, *J. Text. Color. Polym. Sci.*, **21**(1) 131-147 (2024).

22. Jang, J., Bae, J. and Yoon, S.-H. A study on the effect of surface treatment of carbon nanotubes for liquid crystalline epoxide–carbon nanotube composites, *Journal of Materials Chemistry*, **13**(4) 676-681 (2003).

23. Shen, X., Wang, Z., Wu, Y., Liu, X., He, Y.-B. and Kim, J.-K. Multilayer graphene enables higher efficiency in improving thermal conductivities of graphene/epoxy composites, *Nano Lett*, **16**(6) 3585-3593 (2016).

24. Yousefi, N., Lin, X., Zheng, Q., Shen, X., Pothnis, J.R., Jia, J., Zussman, E. and Kim, J.-K. Simultaneous in situ reduction, self-alignment and covalent bonding in graphene oxide/epoxy composites, *Carbon*, **59** 406-417 (2013).

25. Gojny, F.H., Wichmann, M.H.G., U.K€opke, Fiedler, B. and Schulte, K. Carbon nanotube-reinforced epoxy-composites: Enhanced stiffness and fracture toughness at low nanotube content, *Composites Science and Technology*, **64**(15) 2363-2371 (2004).

26. Viets, C., Kaysser, S. and Schulte, K. Damage mapping of gfrp via electrical resistance measurements using nanocomposite epoxy matrix systems, *Composites Part B: Engineering*, **65** 80-88 (2014).

27. Lin, Y. and Connell, J.W. Advances in 2d boron nitride nanostructures: Nanosheets, nanoribbons,

nanomeshes, and hybrids with graphene, *Nanoscale*, **4**(22) 6908-39 (2012).

28. Yao, Y., Lin, Z., Li, Z., Song, X., Moon, K.-S. and Wong, C.-p. Large-scale production of two-dimensional nanosheets, *Journal of Materials Chemistry*, **22**(27) (2012).

29. Lee, D., Lee, B., Park, K.H., Ryu, H.J., Jeon, S. and Hong, S.H. Scalable exfoliation process for highly soluble boron nitride nanoplatelets by hydroxide-assisted ball milling, *Nano Letters*, **15**(2) 1238-1244 (2015).

30. Teng, C., Xie, D., Wang, J., Yang, Z., Ren, G. and Zhu, Y. Ultrahigh conductive graphene paper based on ball- milling exfoliated graphene, *Advanced Functional Materials*, **27**(20) (2017).

31. Gu, J., Guo, Y., Lv, Z., Geng, W. and Zhang, Q. Highly thermally conductive poss-g-sicp/uhmwpe composites with excellent dielectric properties and thermal stabilities, *Composites Part A: Applied Science and Manufacturing*, **78** 95-101 (2015).

32. Castrillo, P.D., Olmos, D., Amador, D.R. and González-Benito, J. Real dispersion of isolated fumed silica nanoparticles in highly filled pmma prepared by high energy ball milling, *Journal of Colloid and Interface Science*, **308**(2) 318-324 (2007).

33. Hanemann, T. and Szabó, D.V. Polymer-nanoparticle composites: From synthesis to modern applications, *Materials*, **3**(6) 3468-3517 (2010).

34. Fan, Q., Ma, J. and Xu, Q. Insights into functional polymer-based organic-inorganic nanocomposites as leather fnishes, *Journal of Leather Science and Engineering*, **1**(1) 1-10 (2019).

35. Hassan, T., Salam, A., Khan, A., Khan, S.U., Khanzada, H., Wasim, M., Khan, M.Q. and Kim, I.S. Functional nanocomposites and their potential applications: A review, *Journal of Polymer Research*, **28**(2) 28-36 (2021).

36. Xu, Q., Ke, X., Shen, L., Ge, N., Zhang, Y., Fu, F. and Liu, X. Surface modification by carboxymethy chitosan via pad-dry-cure method for binding ag nps onto cotton fabric, *Int J Biol Macromol*, **111** 796-803 (2018).

37. Zhang, J., Wang, X.X., Zhang, B., Ramakrishna, S., Yu, M., Ma, J.W. and Long, Y.Z. In situ assembly of well-dispersed ag nanoparticles throughout electrospun alginate nanofibers for monitoring human breath-smart fabrics, *ACS Appl Mater Interfaces*, **10**(23) 19863-19870 (2018).

38. Qin, H., Li, J., He, B., Sun, J., Li, L. and Qian, L. Novel wearable electrodes based on conductive chitosan fabrics and their application in smart garments, *Materials (Basel)*, **11**(3) (2018).

39. Yu, Y., Shen, M., Song, Q. and Xie, J. Biological activities and pharmaceutical applications of polysaccharide from natural resources: A review, *Carbohydr Polym*, **183** 91-101 (2018).

40. Song, Q., Wang, Y., Huang, L., Shen, M., Yu, Y., Yu, Q., Chen, Y. and Xie, J. Review of the relationships among polysaccharides, gut microbiota, and human health, *Food Res Int*, **140** 109858 (2021).

41. Fernandes, M., Gama, M., Dourado, F. and Souto, A.P. Development of novel bacterial cellulose composites for the textile and shoe industry, *Microb Biotechnol*, **12**(4) 650-661 (2019).

42. Chen, F. and Huang, G. Preparation and immunological activity of polysaccharides and their derivatives, *Int J Biol Macromol*, **112** 211-216 (2018).

43. de Jesus Raposo, M.F., de Morais, A.M. and de Morais, R.M. Marine polysaccharides from algae with potential biomedical applications, *Mar Drugs*, **13**(5) 2967-3028 (2015).

44. Li, Q., Niu, Y., Xing, P. and Wang, C. Bioactive polysaccharides from natural resources including chinese medicinal herbs on tissue repair, *Chin Med*, **13** 7 (2018).

45. Saveleva, M.S., Eftekhari, K., Abalymov, A., Douglas, T.E.L., Volodkin, D., Parakhonskiy, B.V. and Skirtach, A.G. Hierarchy of hybrid materials-the place of inorganics-in-organics in it, their composition and applications, *Front Chem*, **7** 179 (2019).

46. Lizundia, E., Puglia, D., Nguyen, T.-D. and Armentano, I. Cellulose nanocrystal based multifunctional nanohybrids, *Progress in Materials Science*, **112** (2020).

47. Schmitz, C., Auza, L.G., Koberidze, D., Rasche, S., Fischer, R. and Bortesi, L. Conversion of chitin to defined chitosan oligomers: Current status and future prospects, *Marine Drugs*, **17**(8) (2019).

48. Sarode, S., Upadhyay, P., Khosa, M., Mak, T., Shakir, A., Song, S. and Ullaha, A. Title: Overview of wastewater treatment methods with special focus on biopolymer chitin-chitosan, *International Journal of Biological Macromolecules*, **121** 1086-1100 (2019).

49. Shahadat, M., Azha, S.F., Ismail, S., Shaikh, Z.A. and Wazed, S.A. Treatment of industrial dyes using chitosan-supported nanocomposite adsorbents, The impact and prospects of green chemistry for textile technologypp. 509-539, (2019).

50. Elamri, A., Zdiri, K. and Harzallah, O. Chitosan: A biopolymer for textile processes and products, *Textile Research Journal*, **93**(5-6) 1456-1484 (2022).

51. Hosseini, M., Montazer, M. and Damerchely, R. Enhancing dye-ability and antibacterial features of silk through pre-treatment with chitosan, *Journal of Engineered Fibers and Fabrics*, **8**(3) 102-111 (2013).

52. Kasiri, M.B. and Safapour, S. Natural dyes and antimicrobials for green treatment of textiles, *Environmental Chemistry Letters*, **12**(1) 1-13 (2013).

53. Ke, G., Zhu, K. and Chowdhury, M.H. Dyeing of cochineal natural dye on cotton fabrics treated with oxidant and chitosan, *Journal of Natural Fibers*, **18**(3) 317-329 (2019).

54. Rehman, A., Iqbal, K., Azam, F., Safdar, F., Ashraf, M., Maqsood, H.S. and Basit, A. To enhance the dyeability of cotton fiber with the application of reactive dyes by using chitosan, *The Journal of The Textile Institute*, **112**(8) 1208-1212 (2020).

55. Shahid-ul-Islam, Butola, B.S. and Roy, A. Chitosan polysaccharide as a renewable functional agent to develop antibacterial, antioxidant activity and colourful shades on wool dyed with tea extract polyphenols, *Int J Biol Macromol*, **120**(Pt B) 1999-2006 (2018).

56. Singha, K., Maity, S. and Singha, M. The salt-free dyeing on cotton: An approach to effluent free mechanism; can chitosan be a potential option?, *International Journal of Textile Science*, **1**(6) 69-77 (2013).

57. Yasser, A., Mahmoud, H., Said, M., Aymen, R., Ashraf, Y., Fathallah, A.I., Maamoun, D., Abdelrahman, M.S., Hassabo, A.G. and Khattab, T.A. Multifunctional properties of cotton fabric treated with chitosan and rtv silicone, *J. Text. Color. Polym. Sci.*, **20**(1) 125-130 (2023).

58. El-Zawahry, M.M., Hassabo, A.G., Abdelghaffar, F., Abdelghaffar, R.A. and Hakeim, O.A. Preparation and use of aqueous solutions magnetic chitosan / nanocellulose aerogels for the sorption of reactive black 5, *Biointerf. Res. Appl. Chem.*, **11**(4) 12380 - 12402 (2021).

59. Hebeish, A., Shaarawy, S., Hassabo, A.G. and El-Shafei, A. Eco-friendly multifinishing of cotton through inclusion of motmorillonite/chitosan hybrid nanocomposite, *Der Phar. Chem.*, **8**(20) 259-271 (2016).

60. Hassabo, A.G. and Mohamed, A.L. Multiamine modified chitosan for removal metal ions from their aqueous solution *BioTechnology: An Indian Journal*, **12**(2) 59-69 (2016).

61. El-Zawahry, M.M., Abdelghaffar, F., Abdelghaffar, R.A. and Hassabo, A.G. Equilibrium and kinetic models on the adsorption of reactive black 5 from aqueous solution using eichhornia crassipes/chitosan composite, *Carbohydrate Polymers*, **136** 507-515 (2016).

62. Hassabo, A.G., Reda, E., Ghazal, H. and Othman, H. Enhancing printability of natural fabrics via pre-treatment with polycationic polymers, *Egy. J. Chem.*, **66**(2) 167-181 (2023).

63. Hegazy, B.M., Othman, H. and Hassabo, A.G. Polycation natural materials for improving textile dyeability and functional performance, *J. Text. Color. Polym. Sci.*, **19**(2) 155-178 (2022).

64. Choudhury, A.K.R. Coloration of cationized cellulosic fibers— a review, *AATCC Journal of Research*, **1** 11-19 (2014).

65. CHATHA, S.A.S., HUSSAIN, A.I., ALI, S., SAIF, M.J., MALLHI1, A.I., SAGIR3, M. and NAZ, M.Y. Significance of chitosan to improve the substantivity of reactive dyes, *Journal of the Chilean Chemical Society*, **61** (2016).

66. HAJI, A., QAVAMNIA, S.S. and BIZHAEM, F.K. Salt free neutral dyeing of cotton with anionic dyes using plasma and chitosan treatments, *industria textila*, **67** 109–113 (2016).

67. Mohamed, F.A., Reda, M.M. and Ibrahim, H. Enhancement of dyeing and antimicrobial properties of chitosan and chitosan nanoparticles-treated cotton and viscose fabrics with acid dyes, *Egyptian Journal of Chemistry*, **0**(0) 0-0 (2022).

68. Costa, E.M., Silva, S., Machado, M., Sousa, S.C., Tavaria, F.K. and Pintado, M. Chitosan nanoparticles as bioactive vehicles for textile dyeing: A proof of concept, *Polymers (Basel)*, **14**(22) (2022).

69. Wong, C. and Clapper, J. Encapsulating natural dyes into chitosan-tpp crosslinked nanoparticles: A potential, *Organic Chemistry*, (2022).

70. Abdelslam, S.H., Mashaly, H.M., El-Thalouth, J.I.A., Saad, M.O. and Abdel-Aziz, M.S. An environmental friendly approach in printing of natural fabrics on using chitosan and chitosan nanoparticles, *Egyptian Journal of Chemistry*, **64**(8) 4283 - 4299 (2021).

71. Hebeish, A., Shahin, A.A., Rekaby, M. and Ragheb, A.A. New environment-friendly approach for textile printing using natural dye loaded chitosan nanoparticles, *Egyptian Journal of Chemistry*, **58** 659- 670 (2015).

72. Fu, X., Shen, Y., Jiang, X., Huang, D. and Yan, Y. Chitosan derivatives with dual-antibacterial functional groups for antimicrobial finishing of cotton fabrics, *Carbohydrate Polymers*, **85**(1) 221-227 (2011).

73. Gil, E. and Hudson, S. Stimuli-reponsive polymers and their bioconjugates, *Progress in Polymer Science*, **29**(12) 1173-1222 (2004).

74. Yuan, G. and Cranston, R. Recent advances in antimicrobial treatments of textiles, *Textile Research Journal*, **78**(1) 60-72 (2008).

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

76. Mohamed, A.L. and Hassabo, A.G. Composite material based on pullulan/silane/zno-nps as ph, thermo-sensitive and antibacterial agent for cellulosic fabrics, *Adv. Nat. Sci.: Nanosci. Nanotechnol.*, **9**(4) 045005 (1-9) (2018).

77. Hassabo, A.G., Nada, A.A., Ibrahim, H.M. and Abou-Zeid, N.Y. Impregnation of silver nanoparticles into polysaccharide substrates and their properties, *Carbohydrate Polymers*, **122** 343-350 (2015).

78. Alfei, S. and Schito, A.M. Positively charged polymers as promising devices against multidrug resistant gram-negative bacteria: A review, *Polymers (Basel)*, **12**(5) (2020).

79. ERDOĞAN, S. Textile finishing with chitosan and silver nanoparticles against escherichia coli atcc 8739, *Journal of Natural Sciences*, **21**(1) (2020).

80. Silva, I.O., Ladchumananandasivam, R., Nascimento, J.H.O., Silva, K.K.O.S., Oliveira, F.R., Souto, A.P., Felgueiras, H.P. and Zille, A. Multifunctional chitosan/gold nanoparticles coatings for biomedical textiles, *Nanomaterials (Basel)*, **9**(8) (2019).

81. Korica, M., Peršin, Z., Zemljič, L.F., Mihajlovski, K., Dojčinović, B., Trifunović, S., Vesel, A., Nikolić, T. and Kostić, M.M. Chitosan nanoparticles functionalized viscose fabrics as potentially durable antibacterial medical textiles, *Materials (Basel)*, **14**(13) (2021).

82. Jarach, N., Dodiuk, H. and Kenig, S. Polymers in the medical antiviral front-line, *Polymers (Basel)*, **12**(8) (2020).

83. Shi, Q., Wang, A., Lu, Z., Qin, C., Hu, J. and Yin, J. Overview on the antiviral activities and mechanisms of marine polysaccharides from seaweeds, *Carbohydr Res*, **453-454** 1-9 (2017).

84. Loutfy, S.A., Elberry, M.H., Farroh, K.Y., Mohamed, H.T., Mohamed, A.A., Mohamed, E.B., Faraag, A.H.I. and Mousa, S.A. Antiviral activity of chitosan nanoparticles encapsulating curcumin against hepatitis c virus genotype 4a in human hepatoma cell lines, *Int J Nanomedicine*, **15** 2699-2715 (2020).

85. Mori, Y., Ono, T., Miyahira, Y., Nguyen, V.Q., Matsui, T. and Ishihara, M. Antiviral activity of silver nanoparticle/chitosan composites against h1n1 influenza a virus, *Nanoscale Research Letters*, **8** 93–98 (2013).

86. Hasan, S.M.M., Shahjalal, M., Mridha, J.H. and Alam, A.M.R. Medical textiles: Application of implantable medical textiles, *Global Journal of Medical Research*, **19**(4) 17-24 (2019).

87. Hassabo, A.G., Saad, F., Hegazy, B.M., Elmorsy, H., Gamal, N., Sedik, A. and Othman, H. Intelligent wound dressing textile fabric using various smart materials, *Materials International*, **5**(1) 1-23 (2023).

88. Gouda, M. and Keshk, S.M.A.S. Evaluation of multifunctional properties of cotton fabric based on metal/chitosan film, *Carbohydrate Polymers*, **80**(2) 504-512 (2010).

89. Rehana, M., El-Naggara, M.E., Mashaly, H.M. and Wilken, R. Nanocomposites based on chitosan/silver/clay for durable multi-functional properties of cotton fabrics, *Carbohydr Polym*, **182** 29-41 (2018).

90. .Montaser, A.S. and Mahmoud, F.A. Preparation of chitosan-grafted-polyvinyl acetate metal nanocomposite for producing multifunctional textile cotton fabrics, *International Journal of Biological Macromolecules*, **124** 659-666 (2019).

91. Abbasipour, M., Mirjalili, M., Khajavi, R. and Majidi, M.M. Coated cotton gauze with ag/zno/chitosan nanocomposite as a modern wound dressing, *Journal of Engineered Fibers and Fabrics*, **9**(1) 124-130 (2014).

92. Chandrasekar, S., Vijayakumar, S. and Rajendran, R. Application of chitosan and herbal nanocomposites to develop antibacterial medical textile, *Biomedicine & Aging Pathology*, **4**(1) 59-64 (2014).

93. Ramadan, M.A., Sharawy, S., Elbisi, M.K. and Ghosal, K. Eco-friendly packaging composite fabrics based on in situ synthesized silver nanoparticles (agnps) & treatment with chitosan and/or date seed extract, *Nano-Structures & Nano-Objects*, **22** (2020).

94. Hussien, A. Antimicrobial and uv protection finishing of polysaccharide -based textiles using biopolymer and agnps, *Egyptian Journal of Chemistry*, **63**(7) 1-2 (2020).

95. Shakeri-Zadeh, A., Bashari, A., Kamrava, S.K. and Ghalehbaghi, S. The use of hydrogel/silver nanoparticle system for preparation of new type of feminine tampons, *BioNanoScience*, **6**(4) 284-292 (2016).

96. Mogrovejo-Valdivia, A., Rahmouni, O., Tabary, N., Maton, M., Neut, C., Martel, B. and Blanchemain, N. In vitro evaluation of drug release and antibacterial activity of a silver-loaded wound dressing coated with a multilayer system, *Int J Pharm*, **556** 301-310 (2019).

97. Psidium guajava leave extract as reducing agent for synthesis of zinc oxide nanoparticles and its application to impart multifunctional properties for cellulosic fabrics, *Biointerface Research in Applied Chemistry*, **11**(5) 13535-13556 (2021).

98. Ren, Y., Zhao, J. and Wang, X. Hydrophilic and antimicrobial properties of acrylic acid and chitosan bigrafted polypropylene melt-blown nonwoven membrane immobilized with silver nanoparticles, *Textile Research Journal*, **88**(2) 182-190 (2016).

99. Hatami, M., Sharifi, A., Karimi-Maleh, H., Agheli, H. and Karaman, C. Simultaneous improvements in antibacterial and flame retardant properties of pet by use of bio-nanotechnology for fabrication of high performance pet bionanocomposites, *Environmental Research* (2022).

100. Montaser, A.S., Jlassi, K., Ramadan, M.A., Sleem, A.A. and Attia, M.F. Alginate, gelatin, and carboxymethyl cellulose coated nonwoven fabrics containing antimicrobial agnps for skin wound healing in rats, *Int J Biol Macromol*, **173** 203-210 (2021).

101. Zhou, J., Hu, X., Zhu, Y., Lyu, H., Zhang, L., Fu, F. and Liu, X. A hybrid binder of carboxymethyl chitosan and l-methionine enables a slight amount of ag nps to be durably effective on antibacterial cotton fabrics, *Cellulose*, **26**(17) 9323-9333 (2019).

102. Türemen, M., Demir, A. and Gokce, Y. The synthesis and application of chitosan coated zno nanorods for multifunctional cotton fabrics, *Materials Chemistry and Physics*, **268** (2021).

103. Saleh, S.N., Khaffaga, M.M., Ali, N.M., Hassan, M.S., El-Naggar, A.W.M. and Rabie, A.G.M. Antibacterial functionalization of cotton and cotton/polyester fabrics applying hybrid coating of copper/chitosan nanocomposites loaded polymer blends via gamma irradiation, *Int J Biol Macromol*, **183** 23-34 (2021).

104. Mohamed, A.L. and Hassabo, A.G. Composite material based on pullulan/silane/zno-nps as ph, thermo-sensitive and antibacterial agent for cellulosic fabrics, *Advances in Natural Sciences: Nanoscience and Nanotechnology*, **9**(4) (2018).

105. Kozicki, M., Kolodziejczyk, M., Szynkowska, M., Pawlaczyk, A., Lesniewska, E., Matusiak, A., Adamus, A. and Karolczak, A. Hydrogels made from chitosan and silver nitrate, *Carbohydr Polym*, **140** 74-87 (2016).

106. Said, M.M., Rehan, M., El-Sheikh, S.M., Zahran, M.K., Abdel-Aziz, M.S., Bechelany, M. and Barhoum, A. Multifunctional hydroxyapatite/silver nanoparticles/cotton gauze for antimicrobial and biomedical applications, *Nanomaterials (Basel)*, **11**(2) (2021).

107. Hajimirzababa, H., Khajavi, R., Mirjalili, M. and KarimRahimi, M. Modified cotton gauze with nano-ag decorated alginate microcapsules and chitosan loaded with pvp-i, *The Journal of The Textile Institute*, **109**(5) 677-685 (2017).

108. Sheikh, J. and Bramhecha, I. Multi-functionalization of linen fabric using a combination of chitosan, silver nanoparticles and tamarindus indica l. Seed coat extract, *Cellulose*, **26**(16) 8895-8905 (2019).

109. Ali, F., Khan, S.B., Kamal, T., Alamry, K.A., Asiri, A.M. and Sobahi, T.R.A. Chitosan coated cotton cloth supported zero-valent nanoparticles: Simple but economically viable, efficient and easily retrievable catalysts, *Sci Rep*, **7**(1) 16957 (2017).

110. Awais, Ali, N., Khan, A., Asiri, A.M. and Kamal, T. Potential application of in-situ synthesized cobalt nanoparticles on chitosan-coated cotton cloth substrate as catalyst for the reduction of pollutants, *Environmental Technology & Innovation*, **23** (2021).

111. Ali, N., Awais, Kamal, T., Ul-Islam, M., Khan, A., Shah, S.J. and Zada, A. Chitosan-coated cotton cloth supported copper nanoparticles for toxic dye reduction, *Int J Biol Macromol*, **111** 832-838 (2018).

112. Ibrahim, N.A., Eid, B.M., Abd El-Ghany, N.A. and Mabrouk, E.M. Polyfunctional cotton cellulose fabric using proper biopolymers and active ingredients, *The Journal of The Textile Institute*, **111**(3) 381-393 (2019).

113. Ibrahim, N.A., Eid, B.M., El-Aziz, E.A., Elmaaty, T.M.A. and Ramadan, S.M. Loading of chitosan - nano metal oxide hybrids onto cotton/polyester fabrics to impart permanent and effective multifunctions, *Int J Biol Macromol*, **105**(Pt 1) 769-776 (2017).

114. Yu, X., Pan, Y., Wang, D., Yuan, B., Song, L. and Hu, Y. Fabrication and properties of biobased layer-by-layer coated ramie fabric-reinforced unsaturated polyester resin composites, *Industrial & Engineering Chemistry Research*, **56**(16) 4758-4767 (2017).

115. Hasan, K.M.F., Wang, H., Mahmud, S., Jahid, M.A., Islam, M., Jin, W. and Genyang, C. Colorful and antibacterial nylon fabric via in-situ biosynthesis of chitosan mediated nanosilver, *Journal of Materials Research and Technology*, **9**(6) 16135-16145 (2020).

116. Abka-Khajouei, R., Tounsi, L., Shahabi, N., Patel, A.K., Abdelkafi, S. and Michaud, P. Structures, properties and applications of alginates, *Mar Drugs*, **20**(6) (2022).

117. Ching, S.H., Bansal, N. and Bhandari, B. Alginate gel particles-a review of production techniques and physical properties, *Crit Rev Food Sci Nutr*, **57**(6) 1133-1152 (2017).

118. Ali, M.A., Hassabo, A.G., Seddik, K.M., yahia, s. and Mohamed, N. Characterization of the thermal and physico-mechanical properties of cotton and polyester yarns treated with phase change materials composites, *Egy. J. Chem.*, **65**(13) 21-37 (2022).

119. Zayed, M., Othman, H., Ghazal, H. and Hassabo, A.G. Psidium guajava leave extract as reducing agent for synthesis of zinc oxide nanoparticles and its application to impart multifunctional properties for cellulosic fabrics, *Biointerf. Res. Appl. Chem.*, **11**(5) 13535 - 13556 (2021).

120. 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).

121. 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).

122. Ali, M.A., Seddik, K.M. and Hassabo, A.G. Polyester fibres enhanced with phase change material (pcm) to maintain thermal stability, *Egy. J. Chem.*, **64**(11) 6599 - 6613 (2021).

123. Hassabo, A.G., Mohamed, A.L., Shaarawy, S. and Hebeish, A. Novel micro-composites based on phosphorylated biopolymer/polyethyleneimine/clay mixture for cotton multi-functionalities performance, *Biosci. Res.*, **15**(3) 2568-2582 (2018).

124. 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).

125. Heliopoulos, N.S., Kouzilos, G.N., Giarmenitis, A.I., Papageorgiou, S.K., Stamatakis, K. and Katsaros, F.K. Viscose fabric functionalized with copper and copper alginate treatment toward antibacterial and uv blocking properties, *Fibers and Polymers*, **21**(6) 1238-1250 (2020).

126. Ogunsona, E., Ojogbo, E. and Mekonnen, T. Advanced material applications of starch and its derivatives, *European Polymer Journal*, **108** 570-581 (2018).

127. Nasrollahzadeh, M., Sajjadi, M., Iravani, S. and Varma, R.S. Starch, cellulose, pectin, gum, alginate, chitin and chitosan derived (nano)materials for sustainable water treatment: A review, *Carbohydr Polym*, **251** 116986 (2021).

128. Elkhayat, A.S., El-Shafey, F.K., Mohamed, E.L., Fouad, A.M., shamiea, M.M. and Hassabo, A.G. Eco-friendly biological materials for healthy food packaging, *J. Text. Color. Polym. Sci.*, **21**(2) 373-383 (2024).

129. El-Sayed, E., Othman, H.A. and Hassabo, A.G. Cyclodextrin usage in textile industry, *J. Text. Color. Polym. Sci.*, **18**(2) 111-119 (2021).

130. Ibrahim, N.A., Nada, A.A., Hassabo, A.G., Eid, B.M., Noor El-Deen, A.M. and Abou-Zeid, N.Y. Effect of different capping agents on physicochemical and antimicrobial properties of zno nanoparticles, *Chem. Pap.*, **71**(7) 1365-1375 (2017).

131. Ji, F., Guo, X., Liu, A., Xu, P., Tan, Y., Wang, R. and Hao, L. In-situ synthesis of polypyrrole/silver for fabricating alginate fabrics with high conductivity, uv resistance and hydrophobicity, *Carbohydr Polym*, **270** 118362 (2021).

132. Zhao, X., Li, Q., Li, X., Xia, Y., Wang, B. and Zhao, Z. Antibacterial activity and in vitro cytotoxicity evaluation of alginate-agnp fibers, *Textile Research Journal*, **87**(11) 1377-1386 (2016).

133. Mokhena, T.C. and Luyt, A.S. Development of multifunctional nano/ultrafiltration membrane based on a chitosan thin film on alginate electrospun nanofibres, *Journal of Cleaner Production*, **156** 470-479 (2017).

134. Amani, A., Montazer, M. and Mahmoudirad, M. Low starch/corn silk/zno as environmentally friendly nanocomposites assembling on pet fabrics, *Int J Biol Macromol*, **170** 780-792 (2021).

135. Alagarasan, D., Harikrishnan, A., Surendiran, M., Indira, K., Khalifa, A.S. and Elesawy, B.H. Retracted article: Synthesis and characterization of cuo nanoparticles and evaluation of their bactericidal and fungicidal activities in cotton fabrics, *Appl Nanosci*, **13**(3) 1797 (2023).

136. Raza, Z.A. In situ synthesis and immobilization of nanosilver on knitted cellulose fabric, *Journal of Natural Fibers*, **15**(2) 183-190 (2017).

137. Tahereh, M.A., Negar, M.K. and Abbas, S.S. In situ production and deposition of nanosized zinc oxide on cotton fabric, *Iranian Journal of Chemistry and Chemical Engineering*, **40** (2021).

138. Lim, K.M.R.C.-., Dagalea, F.M.S., Adora, N.M. and Ultra, C.I. Antimicrobial activity of nypa fruticans (nipa) palm starch and zinc oxide nanoparticles (znonps) in textile: Solving the

scarcity using local resources, *Journal of Pharmaceutical Research International*, (32) 84-89 (2020).

139. Salimpour Abkenar, S. and Mohammad Ali Malek, R. Modification of silk yarn with β- cyclodextrin nanoparticles: Preparation, characterization, and natural dyeing properties, *Starch - Stärke*, **73**(7-8) (2021).

140. Pereira, A.G., Mejuto, J.C., Carpena, M., Oliveira, P.G., Prieto, M.A. and Gandara, J.S. Main applications of cyclodextrins in the food industry as the compounds of choice to form host-guest complexes, *International Journal of Molecular Sciences*, **22**(3) (2021).

141. Elsayed, G.A. and Hassabo, A.G. Insect repellent of cellulosic fabrics (a review), *Letters in Applied NanoBioScience*, **11**(1) 3181 - 3190 (2022).

142. Keshavarz, A.H., Montazer, M. and Soleimani, N. In situ synthesis of polyamidoamine/β-cyclodextrin/silver nanocomposites on polyester fabric tailoring drug delivery and antimicrobial properties, *Reactive and Functional Polymers*, **152** (2020).

143. Hedayati, N., Montazer, M., Mahmoudirad, M. and Toliyat, T. Cotton fabric incorporated with β-cyclodextrin/ketoconazole/ag nps generating outstanding antifungal and antibacterial performances, *Cellulose*, **28**(12) 8095-8113 (2021).

144. SARI, C. and ARIK, B. The comparison of the effects of β-cyclodextrin complex and derivative complex with silver nanoparticles on cotton fabric, (2021).

145. Attarchi, N., Montazer, M., Toliyat, T., Samadi, N. and Harifi, T. Novel cellulose fabric with multifunctional properties through diverse methods of ag/tio2/β-cyclodextrin nanocomposites synthesis, *Cellulose*, **25**(2) 1449-1462 (2017).

146. Mogrovejo-Valdivia, A., Maton, M., Garcia-Fernandez, M.J., Tabary, N., Chai, F., Neut, C., Martel, B. and Blanchemain, N. In vitro microbiological and drug release of silver/ibuprofen loaded wound dressing designed for the treatment of chronically infected painful wounds, *Antibiotics (Basel)*, **10**(7) (2021).

147. Zhang, C.Q., Wang, Y.M., Li, S.Z., Feng, X.D., Liu, L.H., Wang, Y., Zhao, L.P. and Zhang, X. Electrospinning and catalytic properties of cyclodextrin functionalized polyoxymethylene (pom) nanofibers supported by silver nanoparticles, *Advances in Polymer Technology*, **2021** 1-9 (2021).

148. Nouri, A., Yaraki, M.T., Ghorbanpour, M., Agarwal, S. and Gupta, V.K. Enhanced antibacterial effect of chitosan film using montmorillonite/cuo nanocomposite, *Int. J. Biol. Macromol.*, **109** 1219-1231 (2018).

149. Akbariazam, M., Ahmadi, M., Javadian, N. and Mohammadi Nafchi, A. Fabrication and characterization of soluble soybean polysaccharide and nanorod-rich zno bionanocomposite, *Int J Biol Macromol*, **89** 369-75 (2016).

150. Usman, A., Hussain, Z., Riaz, A. and Khan, A.N. Enhanced mechanical, thermal and antimicrobial properties of poly(vinyl alcohol)/graphene oxide/starch/silver nanocomposites films, *Carbohydr Polym*, **153** 592-599 (2016).

151. Kumar, S., Krishnakumar, B., Sobral, A. and Koh, J. Bio-based (chitosan/pva/zno) nanocomposites film: Thermally stable and photoluminescence material for removal of organic dye, *Carbohydr Polym*, **205** 559-564 (2019).

152. Jafarzadeh, S., Ariffin, F., Mahmud, S., Alias, A.K., Hosseini, S.F. and Ahmad, M. Improving the physical and protective functions of semolina films by embedding a blend nanofillers (zno-nr and nano-kaolin), *Food Packaging and Shelf Life*, **12** 66-75 (2017).

153. Perumal, A.B., Sellamuthu, P.S., Nambiar, R.B. and Sadiku, E.R. Development of polyvinyl alcohol/chitosan bio-nanocomposite films reinforced with cellulose nanocrystals isolated from rice straw, *Applied Surface Science*, **449** 591-602 (2018).

154. Koosha, M. and Hamedi, S. Intelligent chitosan/pva nanocomposite films containing black carrot anthocyanin and bentonite nanoclays with improved mechanical, thermal and antibacterial properties, *Progress in Organic Coatings*, **127** 338-347 (2019).

155. Mujtaba, M., Salaberria, A.M., Andres, M.A., Kaya, M., Gunyakti, A. and Labidi, J. Utilization of flax (linum usitatissimum) cellulose nanocrystals as reinforcing material for chitosan films, *Int J Biol Macromol*, **104**(Pt A) 944-952 (2017).

156. Salari, M., Sowti Khiabani, M., Rezaei Mokarram, R., Ghanbarzadeh, B. and Samadi Kafil, H. Development and evaluation of chitosan based active nanocomposite films containing bacterial cellulose nanocrystals and silver nanoparticles, *Food Hydrocolloids*, **84** 414-423 (2018).

157. Antoniou, J., Liu, F., Majeed, H. and Zhong, F. Characterization of tara gum edible films incorporated with bulk chitosan and chitosan nanoparticles: A comparative study, *Food Hydrocolloids*, **44** 309-319 (2015).

158. Wu, C., Li, Y., Du, Y., Wang, L., Tong, C., Hu, Y., Pang, J. and Yan, Z. Preparation and characterization of konjac glucomannan-based bionanocomposite film for active food packaging, *Food Hydrocolloids*, **89** 682-690 (2019).

159. Shankar, S. and Rhim, J.-W. Preparation and characterization of agar/lignin/silver nanoparticles

composite films with ultraviolet light barrier and antibacterial properties, *Food Hydrocolloids*, **71** 76-84 (2017).

160. Klemm, D., Cranston, E.D., Fischer, D., Gama, M., Kedzior, S.A., Kralisch, D., Kramer, F., Kondo, T., Lindström, T., Nietzsche, S., Petzold-Welcke, K. and Rauchfuß, F. Nanocellulose as a natural source for groundbreaking applications in materials science: Today's state, *Materials Today*, **21**(7) 720-748 (2018).

161. Bacakova, L., Pajorova, J., Bacakova, M., Skogberg, A., Kallio, P., Kolarova, K. and Svorcik, V. Versatile application of nanocellulose: From industry to skin tissue engineering and wound healing, *Nanomaterials (Basel)*, **9**(2) (2019).

162. Li, S. and Lee, P.S. Development and applications of transparent conductive nanocellulose paper, *Sci Technol Adv Mater*, **18**(1) 620-633 (2017).

163. Bacakova L., P.J., Bacakova M., Skogberg A., Kallio P., Kolarova K., Svorcik V. Versatile Application of nanocellulose: From industry to skin tissue engineering and wound healing., *Nanomaterials (Basel)*, (2019).

164. Ragab, M.M., Othman, H. and Hassabo, A.G. Utilization of regenerated cellulose fiber (banana fiber) in various textile applications and reinforced polymer composites, *J. Text. Color. Polym. Sci.*, **21**(Special Issue) 537-557 (2024).

165. Othman, H., Ebrahim, S.A., Reda, E.M., Mamdouh, F., Yousif, A.a.R. and Hassabo, A.G. Focus on bamboo and its physical, chemical properties, and dyeing methods, *J. Text. Color. Polym. Sci.*, **21**(2) 293-312 (2024).

166. Khalid, N., Othman, H. and Hassabo, A.G. Manufacturing and usage of lyocell fabric, *Egy. J. Chem.*, **67**(13) 151-157 (2024).

167. 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).

168. El-Zawahry, M.M., Hassabo, A.G. and Mohamed, A.L. Preparation of cellulose gel extracted from rice straw and its application for metal ion removal from aqueous solutions, *Int. J. Biol. Macromol.*, **248** 125940 (2023).

169. 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).

170. Saad, F., Hassabo, A., Othman, H., Mosaad, M.M. and Mohamed, A.L. A valuable observation on thickeners for valuable utilisation in the printing of different textile fabrics, *Egy. J. Chem.*, **65**(4) 431 – 448 (2022).

171. Ragab, M.M., Othman, H.A. and Hassabo, A.G. Various extraction methods of different enzymes and their potential applications in various industrial sector (a review), *Egy. J. Chem.*, **65**(10) 495 - 508 (2022).

172. Mohamed, A.L. and Hassabo, A.G. Modified cellulose acetate membrane for industrial water purification, *Egy. J. Chem.*, **65**(13) 53-70 (2022).

173. Hassabo, A.G., Shaarawy, S., Mohamed, A.L. and Hebiesh, A. Multifarious cellulosic through innovation of highly sustainable composites based on moringa and other natural precursors, *Int. J. Biol. Macromol.*, **165** 141-155 (2020).

174. McCune, D., Guo, X., Shi, T., Stealey, S., Antrobus, R., Kaltchev, M., Chen, J., Kumpaty, S., Hua, X., Ren, W. and Zhang, W. Electrospinning pectin-based nanofibers: A parametric and cross-linker study, *Applied Nanoscience*, **8**(1-2) 33-40 (2018).

175. Wolf, S., Mouille, G. and Pelloux, J. Homogalacturonan methyl-esterification and plant development, *Mol Plant*, **2**(5) 851-60 (2009).

176. Alipour, R., Khorshidi, A., Shojaei, A.F., Mashayekhi, F. and Moghaddam, M.J.M. Skin wound healing acceleration by ag nanoparticles embedded in pva/pvp/pectin/mafenide acetate composite nanofibers, *Polymer Testing*, **79** (2019).

177. Saad, M.A.O., Hassabo, A.G., znatii, a., muhammad, m. and mostafa, s. Pectin as organic framework for znonps to enhance the functionality of textile printed fabrics, *J. Text. Color. Polym. Sci.*, **21**(Special Issue) 509-518 (2024).

178. Hassabo, A.G., Ebrahim, S., Othman, H.A. and Mosaad, M.M. Using pectin to enhance the dyeability performance and antimicrobial activity using different dyes on modified proteinic and synthetic fabrics, *Biointerf. Res. Appl. Chem.*, **13**(5) BRIAC135.467 (2023).

179. Ebrahim, S.A., Othman, H.A., Mosaad, M.M. and Hassabo, A.G. Eco-friendly natural thickener (pectin) extracted from fruit peels for valuable utilization in textile printing as a thickening agent, *Textiles*, **3**(1) 26-49 (2023).

180. Ebrahim, S.A., Othman, H.A., Mosaad, M.M. and Hassabo, A.G. A valuable observation on pectin as an eco-friendly material for valuable utilisation in textile industry, *Egy. J. Chem.*, **65**(4) 555 – 568 (2022).

181. 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).

182. Liu, R., Dai, L., Si, C. and Zeng, Z. Antibacterial and hemostatic hydrogel via nanocomposite from cellulose nanofibers, *Carbohydr Polym*, **195** 63-70 (2018).

183. Nechyporchuk, O., Yu, J., Nierstrasz, V.A. and Bordes, R. Cellulose nanofibril-based coatings of woven cotton fabrics for improved inkjet printing with a potential in e-textile manufacturing, *ACS Sustainable Chemistry & Engineering*, (2017).

184. Li, M., Farooq, A., Jiang, S., Zhang, M., Mussana, H. and Liu, L. Functionalization of cotton fabric with zno nanoparticles and cellulose nanofibrils for ultraviolet protection, *Textile Research Journal*, **91**(19-20) 2303-2314 (2021).

185. Cloud, R.M., Cao, W. and Song, G. Functional finishes to improve the comfort and protection of apparel, Advances in the dyeing and finishing of technical textilespp. 258-279, (2013).

186. Kale, B.M., Wiener, J., Militky, J., Rwawiire, S., Mishra, R., Jacob, K.I. and Wang, Y. Coating of cellulose-tio2 nanoparticles on cotton fabric for durable photocatalytic self-cleaning and stiffness, *Carbohydr Polym*, **150** 107-13 (2016).

187. Price, R.D., Berry, M.G. and Navsaria, H.A. Hyaluronic acid: The scientific and clinical evidence, *J Plast Reconstr Aesthet Surg*, **60**(10) 1110-9 (2007).

188. El-Aassar, M.R., Ibrahim, O.M., Fouda, M.M.G., El-Beheri, N.G. and Agwa, M.M. Wound healing of nanofiber comprising polygalacturonic/hyaluronic acid embedded silver nanoparticles: In-vitro and in-vivo studies, *Carbohydr. Polym.*, **238** 116175 (2020).

189. Dionisio, M. and Grenha, A. Locust bean gum: Exploring its potential for biopharmaceutical applications, *J Pharm Bioallied Sci*, **4**(3) 175-85 (2012).

190. Elnaggar, M., Emam, H., Fathalla, M., Abdel-Aziz, M. and Zahran, M. Chemical synthesis of silver nanoparticles in its solid state: Highly efficient antimicrobial cotton fabrics for wound healing properties, *Egyptian Journal of Chemistry*, **0**(0) 0-0 (2021).

191. Marques, M.S., Zepon Kappa, M., Heckler, J.M., Morisso, F.D.P., da Silva Paula, M.M. and Kappaanis, L.A. One-pot synthesis of gold nanoparticles embedded in polysaccharide-based hydrogel: Physical-chemical characterization and feasibility for large-scale production, *Int J Biol Macromol*, **124** 838-845 (2019).

192. Mohamed, A.L., El-Naggar, M.E., Shaheen, T.I. and Hassabo, A.G. Novel nano polymeric system containing biosynthesized core shell silver/silica nanoparticles for functionalization of cellulosic based material, *Microsystem Technologies*, **22**(5) 979-992 (2015).

193. Eghbalifam, N., Shojaosadati, S.A., Hashemi-Najafabadi, S. and Khorasani, A.C. Synthesis and characterization of antimicrobial wound dressing material based on silver nanoparticles loaded gum arabic nanofibers, *Int J Biol Macromol*, **155** 119-130 (2020).

التطورات في مركبات البوليمر النانوية: التركيب والخصائص والإمكانات المستقبلية

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المستخلص

أصبح علم المواد أكثر شعبية وفائدة، مع وجود طلب كبير على المواد المركبة التي تجمع بين أفضل سمات كلا المكونين. وقد أحدثت مركبات البوليمر النانوية مؤخرًا ضجة كبيرة في وسائل الإعلام وفي مجموعة متنوعة من الصناعات. وكان هناك الكثير من الاهتمام بتعديل بنية وتكوين المواد على مقياس النانومتر في جميع أنحاء العالم في السنوات الأخيرة. نتيجة لذلك، فإن الفحص الدقيق لإنتاج وخصائص وتطبيقات النانو مركبات البوليمرية أمر ضروري. يتم تصنيف النانو مركبات البوليمرية إلى أنواع عديدة اعتمادًا على مجموعة متنوعة من الخصائص. يتم استخدام طريقة هلام السول، والبلمرة في الموقع، وخلط المحلول، وخلط الذوبان، والبلمرة التداخلية في الموقع في التحضير. تم البحث على نطاق واسع في الخصائص الميكانيكية والبصرية والروموليجية ومقاومة اللهب والعزل للمركبات النانوية. أخيرًا، تم استكشاف التطبيقات المهمة للمركبات النانوية، بالإضافة إلى إمكاناتها المستقبلية.

الكلمات المفتاحية: تكنولوجيا النانو، التخليق، البوليمر النانوي، التطبيق