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*Review Article*

# Chitosan Superabsorbent Biopolymers in Sanitary and Hygiene Applications

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The consumption of diapers and sanitary products has constantly been rising. Several problems are associated with using chemical-based sanitary products, which are difficult to degrade easily and cause nappy rash and bacterial infections in babies. Therefore, there is an increasing shift towards natural-based sanitary products because of their biodegradability, non-toxicity, and biocompatibility. Several studies are being carried out in which researchers have incorporated natural polymers, such as cellulose, starch, alginate, and xantham gum for producing superabsorbent materials. Chitosan (CS) is one such natural polymer that exhibits anti-microbial activity because of the functional groups present in its structure. Moreover, it is also easily available, biodegradable, and non-toxic. This review mainly focuses on CS's properties and several approaches to synthesizing natural polymer-based superabsorbent products, such as sanitary pads and diapers. It also briefly discusses the diversified applications of CS as a biopolymer in the cosmetic, medical, food, and textile industries. In addition, this study implies using CS as a superabsorbent biopolymer in the manufacturing and producing sanitary products for women and children. Due to the excellent water retention capacity, swelling ability, and anti-microbial activity exhibited by CS can be considered a potential candidate for producing superabsorbent biopolymers.

## 1. Introduction

Diapers were originally invented in the 1930s; according to Sasikumar et al., an average diaper weighs between 1.4 and 1.8 Oz. It is generally composed of cellulose, polypropylene, polyethylene, and a super absorbent polymer, along with trace amounts of adhesives, tapes, and elastic materials [1]. They have been improvised tremendously, thereby eradicating the problems, such as improperly fitting inners made up of terry cloth and constant contact with urine and water. Disposable diapers generally comprise a polypropylene top sheet, a superabsorbent polymers (SAP) or cellulose absorbent core, and a polyethylene back sheet. These components can be either synthetic or natural. The top sheet consists of hydrophobic and hydrophilic parts, wherein the hydrophobic part acts as leak guards and the hydrophilic part is in contact with the skin and helps transfer the urine to the absorbent core. The absorbent core materials mainly subsist on SAP and wood pulp. The innermost layer of the diaper ensures that the urine and fecal matter remain trapped inside. SAPs are functional materials mainly composed of a cross-linked hydrophilic polymer of acrylic acid (AA) blended with sodium hydroxide forming a poly-acrylic acid sodium salt in a loose three-dimensional network. SAPs have various applications, such as manufacturing and producing diapers, cosmetics, and absorbent pads. SAPs can be broadly classified into two broad categories: synthetic SAPs—mainly composed of petrochemicals and natural SAPs—are biopolymers. The back sheet is composed of polyethylene that allows air and water vapour to pass through, keeping the skin dry for a longer period.

Most of the commercially available superabsorbent disposable diapers in the market are composed of petroleum-based vinyl monomers that are difficult to degrade and are a menace to the environment [2]. SAPs have numerous potential applications. The most prevalent ones were in disposable personal hygiene items like feminine napkins, adult incontinence products, and baby diapers. Other applications include agriculture and forestry. With developments in polymer synthesis resulting in increased water absorption capacity, stronger gel strength, faster absorption rate, and biodegradability, as well as other material qualities for comfort and safety, biodegradable SAPs are one of the most active study fields in polymer sciences [3]. Studies conducted by Khoo et al. stated that disposable diapers are the third largest consumed product, and they contribute around 30% of non-biodegradable waste in landfills because they take more than 500 years to decompose they serve as a breeding ground for a large range of viruses and bacteria [4]. Ntekpe et al., in their study, concluded that due to the lengthy decomposition period when these diapers containing fecal matter are disposed of into garbage, lack of treatment of human fecal matter results in the growth of bacteria and viruses, which leaches into the groundwater supply, thereby contaminating it, and this adds on the already existing tons of waste. A large number of disposable diapers are required for a baby in his/her lifetime, which not only involves a good amount of money for manufacturing but also for their disposal. This increases the burden on landfill sites. After its disposal in the landfill, heavy metals, dioxins, phthalates, sodium polyacrylate (SPA), and other toxic substances leach into the soil and water. These chemicals get deposited in fishes and other aquatic life forms. The continuous accumulation of dioxin and SPA in the biota disrupts the food chain and causes bioaccumulation and biomagnification. If the diaper is not disposed of properly, it may leak droplets. As a consequence of this, microorganisms can be transmitted to humans as well as surfaces. Several infectious diseases, such as polio and hepatitis, are caused by viruses, such as entero-viruses and adenoviruses, and bacterial pathogens, such as *Shigella* and *Escherichia coli* species, which are generally present in the human excreta [5].

With the increasing demand for environmental protection and green chemistry, biodegradable materials are an important area of research. Therefore, Cheng et al. leaned towards renewable and biodegradable polymers mainly because of their ample availability and low cost of production. Nowadays, eco-friendly superabsorbent hydrogels are being developed from natural polymers, such as rice husk, starch, chitosan (CS), and cellulose. Studies showed that high water uptake was exhibited by CS starch citrate cross-linked polymer in water and saline medium [2].

CS is cationic, a linear polysaccharide comprising a variable degree of *N*-acetylation and a deacetylated chitin (CH) derivative [6]. CH is the second most generously available natural polymer, following cellulose. It is present as an exoskeleton in crustaceans, insects' cuticles, and fungal cell walls [7]. The prospect of spiders (order Araneae) as an alternate source of tubular CH has been neglected in favour of marine crustaceans and sponges. A naturally manufactured, renewable supply of tubular CH with significant potential for use in technology and healthcare is this spider's tube-like moult cuticle [8]. Figure 1 demonstrates the several sources from which CS can be obtained. CS is a potential candidate for the synthesis of SAP, owing to the presence of amino($-NH_3$) and carboxyl ($-COOH$) groups in the backbone. Due to the presence of these groups, graft polymerization of hydrophilic vinyl monomer chains onto CS is convenient, making this an efficient way to synthesize hydrogels that are more biodegradable. Figure 2 provides the basic structure of CS. Assuming that we can assemble pure CS into SAP without any modifications, it would be favorable to human health and the environment. CS is derived from a renewable resource and is anti-viral. It was also reported as an immune enhancer. CS nanoparticles attached to viscose cellulose fibres were prepared to be used as a potential vaginal drug delivery system. The ionic gelation technique synthesized CS nanoparticles [10]. Biopolymers like CS have low ductility, but better mechanical and degradation properties. It is reported that low Degree of deacetylation (DD) of CS gives rise to faster biodegradation, so the selection of DD of CS is critical [11] More than 200 years after its discovery, research on CH production in many phyla is still in demand, as is its practical use in biomedicine, technology, and biomimicry. CH is difficult to identify since it is not found in nature in a pure form but rather as nanoorganized CH proteins, CH-pigments, or CH–mineral composite biomaterials. Therefore, the advancement of contemporary CH-related technologies and illness diagnostics depended heavily on the development of very sensitive analytical methods for its identification [12].

## 2. Understanding CS Biopolymer

Absorbent hydrogel made from CS, AA, and Chitosan/Cellulose Nanocomposites (CNC) exhibited a 100-unit increase in swelling capacity, from 381 to 486, with faster equilibrium [13]. Cassava starch, CS, and AA synthesized superabsorbent hydrogel. The maximal swelling capacities of the graft polymers were 670 g/g—in distilled water, 520 g/g—in NaCl solution, and 767 g/g—in urea solution compared with the dry weight [14]. Polysaccharide-based superabsorbent nanocomposites were prepared using CH, CS, starch, and other cellulose derivatives due to their exceptional swelling indices, stimuli responsiveness, biodegradability, biocompatibility, and non-toxicity. Hydrogels are promising materials for pharmaceutical, agricultural, and wastewater management, primarily dye and heavy metal removal and biotechnological applications, particularly in making superabsorbent

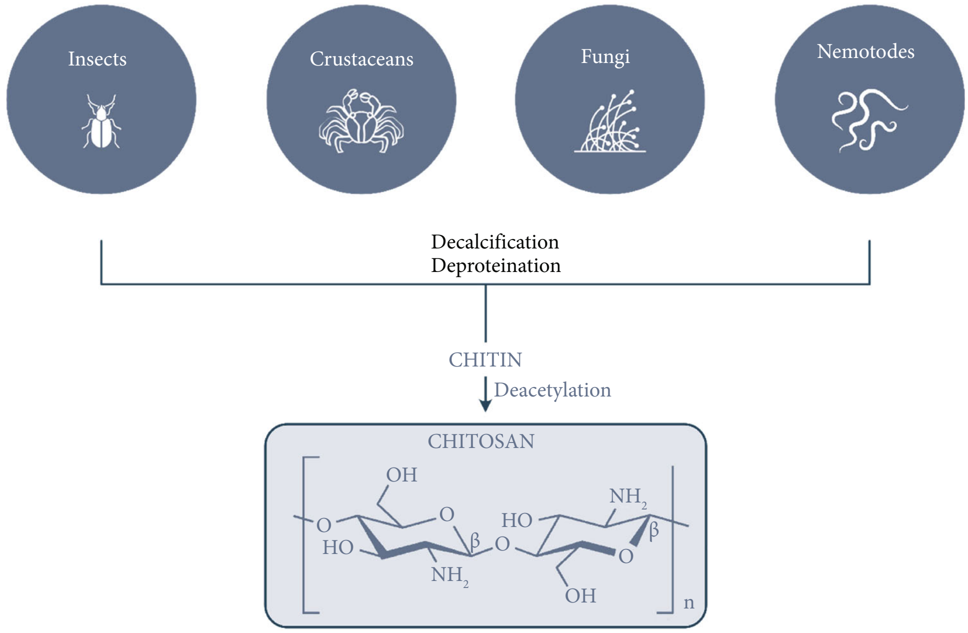


FIGURE 1: Sources and extraction of chitosan [9].

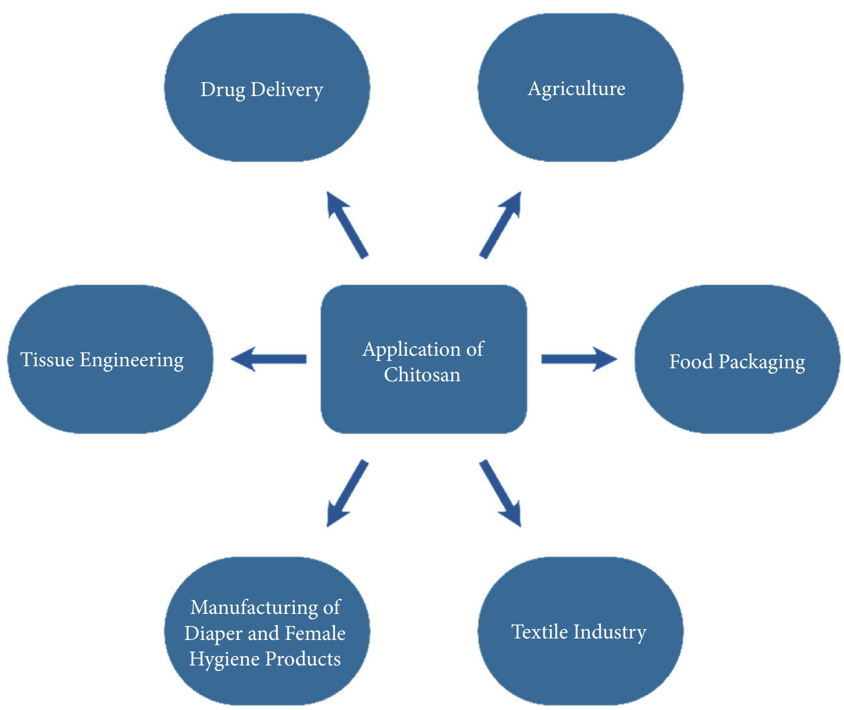


FIGURE 2: Applications of chitosan.

materials [15]. The degree of cross-linking affected both swelling capacities as well as sorption rate. Although cross-linking was necessary to stop the polymer from dissolving, a high cross-linking percentage made the polymer more compact and less prone to swelling [16]. Superabsorbent hydrogel based on CS-graft-poly(acrylic acid)/rice husk ash was synthesized; the swelling capacity in a range of solutions with varying pH (2–12), and the swelling and deswelling behavior of the hydrogel showed considerable sensitivity to pH. By raising cross-linker concentration from 1 to 3 wt%, the swelling was reduced because the hydrogels' cross-linking density increased, making them more rigid. The development of more active sites led to increased chains grafted with Poly acrylic acid (PAA) onto the backbone of Chitosan (CTS) and enhanced water absorption when the initiator amount was increased from 1 to 3 wt%. The produced hydrogel composites showed a noticeable swelling when placed in various salt solutions, particularly those containing monovalent cations [17]. Sadeghi et al. developed a novel hydrogel comprising Acrylamide and N-isopropylacrylamide (NIPAAm), which showed the greatest swelling capacity at pH 8. Some carboxylate groups got ionized at higher pHs (5–8), which increased the swelling capacity because of the electrostatic attraction between the carboxyl groups. Hydrogels' capacity to absorb water was evaluated in solutions with pH ranges of 1–13. A pulsatile swelling–deswelling behavior was seen at pH 3 and 8 because CS-based hydrogel had a pH-responsiveness characteristic [18]. Zhang et al., in their study, developed a CS-g-poly(acrylic acid)/montmorillonite superabsorbent composite with a relatively porous surface that helped with the swelling. More AA molecules could become available near the CTS macroradicals when the weight ratio of AA to CTS was increased, which improved the water absorbency and increased the hydrophilicity of the superabsorbent nanocomposite [19]. The modified CS-based novel superabsorbent hydrogel was reported by Oladipo, due to the presence of hydrophilic chains of polyacrylamide in the backbone of superabsorbent hydrogel and higher water retention capacity of DHPC-GMA-gPAAm; the highest swelling percentages of 1897.2%, 1507.1%, and 1432.2% were attained after 50 hours [20]. Based on crocin loaded with biopolymers of CS and alginate, nanoparticles were synthesized by Rahaiee et al. The presence of CS in nanoparticles exhibited relatively high swelling in acidic pH than intestinal pH indicating that the swelling behavior was pHsensitive [21]. The LaCs (LaC+ incorporated CS) membrane's swelling ratio was 57.6%, owing to both amino and hydroxyl groups in CS molecules, and attracts water through hydrogen bonding [22]. Mahdavinia et al. reported modified CS,and the swelling property of this modified CS depended on the rise in the concentration of ionizable groups, which are functional in the network, and decreased cross-linking. In saline solutions, swelling capacity decreased due to perfect anion–anion electrostatic repulsion. CS-based superabsorbent was less sensitive to ionic strength than commercial full synthetic superabsorbent. Since both acidic and basic groups exist, they act as ampholytic with pH-responsiveness in swelling behavior [23]. Bayat Tork et al. reported that polyvinyl alcohol (PVA) and CS are biopolymers that can replace tampons as they are biocompatible and non-toxic, and have swelling properties [24]. CS was blended with potassium hydroxide to produce a superabsorbent poly(acrylic acid)-graft-CS hydrogel through gamma irradiation. This hydrogel displayed the best swelling capacity in water and dye solutions [25]. Alginate-carboxy methyl cellulose superabsorbent prepared by a novel quasi cryogelation method showed good water absorption properties, with water absorption reaching 2343% and remaining at 1200% after four cycles [26]. With the cross-linker molecule being biodegradable, *N*-maleylCS, acrylamide (AM), and AA serving as monomers, and ammonium peroxydisulphate-sodium bisulphite ($NaHSO_3$) acting as a redox initiation system, a high-swelling superabsorbent was created using aqueous solution polymerization. Under ideal circumstances, the water retention capacity of the superabsorbent produced was 92.7, 1, and 812 g/g in 0.9% salt solution and distilled water, respectively [27]. Membrane-based CS, which is bioactive, biocompatible, and biodegradable, has a lot of potential for use as a substrate in in vitro mineralization procedures. Upon implantation, it only causes a minor foreign body reaction and fibrous encapsulation, and it biodegrades by hydrolyzing acetylated residues under the influence of lysozyme. CS, which has been neglected up until now, is an appealing starting material for a wide range of biomedical and biorelated applications because of its very advantageous biological and chemical properties. CS's unique capacity to act as templates for successive mineralization in the form of membranes opens up new perspectives on the partial processes of in vivo biomineralization reactions and creates a new foundation for biomimetic mineralization of biopolymers for usage in a variety of applications, particularly for bone tissue engineering [28].

## 3. Biodegradability of CS

Narayanan et al. synthesized super absorbing polymeric gel using CS and citric acid along with urea in the weight ratio of 1 : 2 : 2. Since a major portion of CHCAUR was made up of CS, it was biodegradable in soil, making it a promising alternative to diapers sold in the market [55]. CS is non-toxic, is low cost, has easy film-forming properties, and is biocompatible and biodegradable [44]. Chadha et al. reported CS as anti-bacterial, anti-fungal, biodegradable, bio-compatible, non-volatile, non-toxic, and potential to increase shelf life. It is environment-friendly and safe for the body. Food and Drug Administration has approved food packaging, CS-based, for preserving food and biodegradable films. Thus, CS can be employed as an edible packing material through spraying, dipping, and spreading techniques [56]. Morin-Crini et al. stated that CS and its derivatives offer a diverse range of distinctive applications in the food industry, including food preservation against microbial degradation, extending the shelf-life extension, developing of biodegradable films, and packaging food (see Figure 3). Moreover, CS was regarded as a suitable substitute for polymers, which do not degrade easily and are not renewable, as a source of preservative for food due to its anti-bacterial and film-formation properties, which also reduced the excessive use of toxic pesticides in food protection [52]. Natural cellulose–CS cross-linked superabsorbent hydrogels were developed by Alam and Christopher. These hydrogels were labeled as "green" superabsorbent due to their biodegradable makeup and environmentally friendly cross-linking method [47]. Maleyl CS-cross-linked poly (acrylic acid-co-acrylamide) superabsorbents were found to be biodegradable [27]. Table 1 represents the diverse range of applications of CS as a biopolymer in various fields, such as medical, textile, and food industries, whereas medical applications are further elaborated in Figure 4. Understanding that CS is a polymer harbouring amino groups as well as a polysaccharide with breakable glycosidic linkages is crucial when discussing the biodegradability of CS.

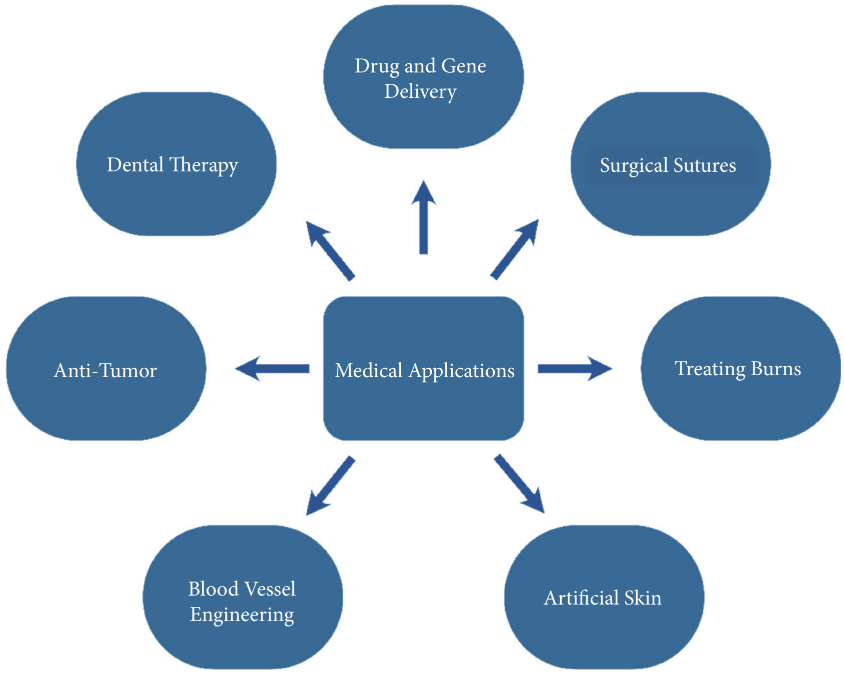


Figure 3: Medical applications of chitosan-based superabsorbents.

The by-products of degradation are non-toxic oligosaccharides that can then be either expelled or added to glycosaminoglycans and glycoproteins. The molecular weight, deacetylation level, polydispersity, purity, and moisture content all play a significant part in the rate of deterioration. Typically, the random splitting of -1,4-glycosidic bonds precedes the hydrolysis of the *N*-acetyl linkage as the potential mechanism of CS degradation. By means of oxidation, chemical breakdown, or enzymatic hydrolysis, CS degrades in vitro. Under regulated circumstances, these techniques are frequently employed to prepare low molecular CS. The distribution of acetyl residues along the CS chain also affects the crystallinity of CS and, as a result, the rate of biodegradation. It is reasonable to draw the conclusion that lower molecular mass CS is biodegraded more effectively than larger molecular mass CS [57].

## 4. Approaches for Synthesizing Natural Polymer-Based Superabsorbent Products: Sanitary Pads and Diapers

Hydrogel nanocomposites of Silver nanoparticles (AgNPs)/CS/PVA/Polyethylene glycol (PEG) prepared via the g-irradiation method are synthesized to use as an upgradation to the tampons. CS solution is prepared to which PVA is added, and then, PEG and $AgNO_3$ are added to this mixture. The tampons are soaked in this solution and later irradiated using a CO-60 gamma-ray source as a model. CS reduced the density of the hydrogel's cross-linking, crystallinity, and H-bonds. Thus, this gives free volumes in the polymer network and increases water absorption [24]. Sodium carboxymethyl cellulose (NaCMC) and starch were used to form superabsorbent membranes. The method adopted was lyophilization and phase inversion, using a consolidation of sodium trimetaphosphate and aluminum sulphate as cross-linker. NaCMC is chosen due to the complex network of hydrogen bonds present, which will stabilize the napkins after absorbing fluids. The developed product is polyacrylate-free, biodegradable, and superabsorbent. While lyophilization yielded homogeneously uniform pores, inversion of phase produced porous graded architecture. Due to their porous nature, the membranes produced via lyophilization displayed superior stability and absorbency compared to phase inversion membranes. Various concentrations of cross-linker were tested, out of which the most successful combination of cross-linker was 1 : 1 wt% showing maximum absorbency. To address the saturated sorption capacity of membranes and the sorption kinetics, they were cut into squares and immersed in water and blood for different time intervals. Lyophilized membrane could hold 2 ml of water, and the phase inversion displayed significant swelling 30-fold volume. [59]. Hemicellulose and CS-based biosorbent material was synthesized to desalinate water and removes heavy metals. The Diethylene triamine pentaacetic acid (DTPA) CS material that had been cross-linked offered a lot of promising avenues for its use in environmental engineering [62]. Crosslinking of carboxymethyl CS (CMCS) was done into a gel, which was then concentrated in a rotary evaporator (at 70°C, 85°C, and 100°C) through the process of partial dehydration, frozen at −5°C, −20°C, and −196°C, and then freeze dried. According to the micrographs obtained from Scanning Electron Microscopy (SEM), these SAPs were porous and sponge-like in structure and, after 10 minutes of exposure, absorbed 32 and 35 g/g of urine and saline solutions, respectively [63]. Cellulose acetate (CA) was used as it is a biocompatible polymer. It has easy processability and a low price. To increase water uptake, lignin was

Table 1: Applications of chitosan.

| Materials used | Application | References |
|---|---|---|
| Chitosan, along with collagen, PLGA, PLA, and alginate | Drug delivery, chemotherapeutics, and immunosuppressants | [29] |
| Chitosan | Biocompatibility enables applications in the biomedical sector, whereas their biodegradability permits additional usage in agriculture | [30] |
| Chitosan | When grafted onto the surface of biochar, chitosan could increase the amount of DOM, such as amino and hydroxyl groups, which could be removed from the surface of the material | [9] |
| Chitin, chitosan, and derivatives | Act as carriers of other active compounds due to their technological properties while thinking about their application in cosmetics | [31] |
| Chitosan rinse | Lowers the number of salivary *Streptococcus mutans* and dental plaque production | [32] |
| Biopolymer using a combination of chitosan and nanolignin | Production of cosmetics and cosmeceuticals which had a variety of uses, such as skin lightening, moisturizing, and hair care and treat damage to the skin<br>To create hair products that protect hair and scalp from the environment while possibly stimulating self-repairing structural activity | [33] |
| Chitosan–alginate biopolymers loaded with crocin | Anti-cancer properties, antioxidant, bioavailability, and their potential as drug delivery agents | [21] |
| Chitosan incorporated with $La^{3+}$ | To remove phosphate as well as nitrate ions from different solution | [22] |
| Electrospun chitosan incorporated with poly(vinyl alcohol)/glycerol nanofibres | It has applications in skin care as it has anti-microbial activity | [34] |
| Cellulose acetate/lignin//*N*-vanillidene-phenyl thiazole copper (II) complex | To combat diaper dermatitis for babies | [35] |
| Chitosan powder coatings | Enhance shelf life quality of carrot shreds | [36] |
| Chitosan as an hydrogel | In buccal and oral drug delivery, also in tissue engineering | [37] |
| Chitosan | In textile industry | [38] |
| Chitosan | Food packaging can be enhanced, and it also increases the anti-microbial efficacy | [38] |
| Chitosan, along with other polysaccharides | Film packaging materials | |
| Chitosan | Useful for delivering the drug in ovarian cancer | [39] |
| Cellulose materials functionalized with chitosan | In gynecological applications as they efficiently inhibit pathogenic microbes. Moreover, they do not alter the resident flora and display no cytotoxic effect | [40] |
| Chitosan | The cosmetics industry, the biomedical field for chitosan-based dressings, water engineering, drug delivery systems, and food technology | [41] |
| Chitosan nanoparticles attached to viscose cellulose fibres | Drug delivery | [40] |
| Chitosan-based varnish | Has potential application in patients undergoing fixed orthodontic treatment | [44] |
| Chitosan | Cell ingrowth and osteoconduction | [42] |
| Chitosan | Sizing and de-sizing agent for textile pre-treatment, an auxiliary for dyeing or a binder for printing, anti-shrinkage agent, and antistatic | [43] |
| Chitosan | Manufacturing scaffolds since they are non-toxic and have an absorption capacity | [47] |
| Chitosan | Textile finishing | [44] |
| Chitosan | As a drug carrier via different routes-oral, vaginal, nasal, parental, or injectable | [45] |
| Chitosan | Food packaging, food preservation, and biodegradable films | [46] |
| Superabsorbent hydrogels made of cross-linked cellulose–chitosan | Diapers and hygiene items, wound dressings, soaking pads for meat, and agricultural applications | [47] |
| Chitosan-based SAP | Limits microbial growth, prolongs these items' useful life, and prevents the development of unpleasant diaper odours | [48] |
| Nanocomposite made of chitosan/ZnO/AgNPs/citronella essential oil | Grapes coating | [49] |
| Superabsorbent chitosan-starch hydrogel | Removal of direct red 80 dye | [50] |
| | Reduced bacteria in the oral cavity | [51] |

Table 1: Continued.

| Materials used | Application | References |
|---|---|---|
| A mouthwash made up of nanochitosan and calcium | | |
| Chitosan | In pharmaceuticals, biotechnology, medicine, cosmetics, agriculture, textiles, and environmental chemistry | [52] |
| Chitosan toothpaste | Reduces the number of *S. mutans* | [53] |
| Chitosan nanocomposites reinforced with nanocellulose | Packaging and biomedical applications | [13] |
| Chitosan-based networks from marine sponges | Abosrb uranium from solutions by weak interactions | [54] |

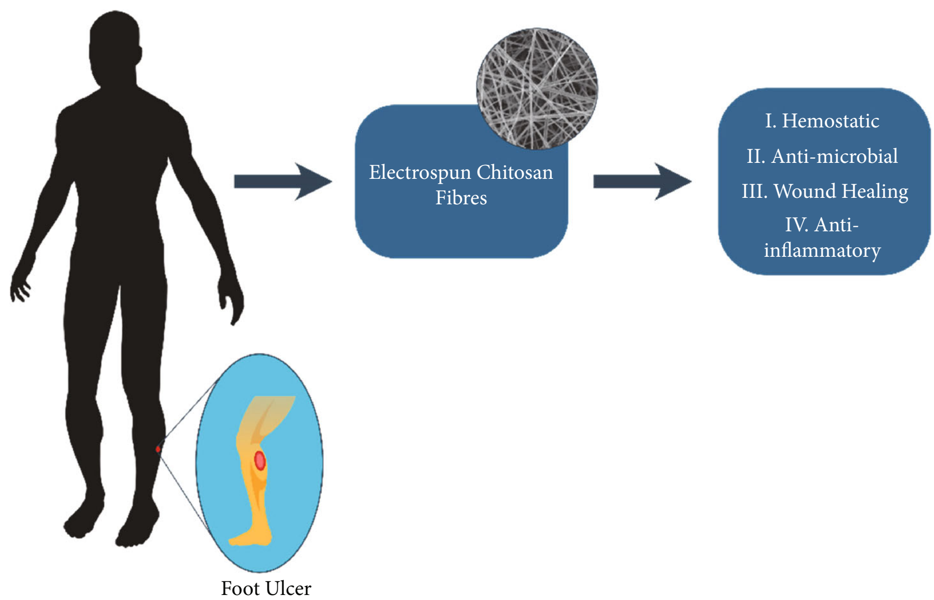


Figure 4: Application of electrospun chitosan fibres in wound healing.

blended with CA. Lignin absorbs water after pulping. Copper complexes were synthesized using *N*-vanillidene-2-amino-thiazole Schiff base derivatives and added to the blend. This copper complex was screened for its antimicrobial activity against *Pseudomonas aeruginosa*, *Staphylococcus epidermidis*, and *Streptococcus faecalis* [35]. CHCAUR, a superabsorbent, was synthesized by preparing CS with citric acid and urea in the ratio of 1 : 2 : 2. The mixture was stirred well for 10 minutes after adding water. The mixture was then kept in a hot air oven at 35–100°C at the rate of 5°C/minutes, followed by isothermal heating at 100°C for 650 minutes. The gel was cooled and then dried in hot air over. Then, it was subjected to mortar and pestle and was grinded to a fine powder. The water absorption was due to the macropores surrounded by a fibrous network of CS molecules which SEM observed [56]. Graft polymerization technique produced superabsorbent composite made up of CS and kaolin powder. The produced superabsorbent composite was biodegradable because of CS and had higher strength and capacity for swelling due to the inorganic parts [64]. Tampons were made using CS. Dry CS powder was converted to a CS-acid solution and applied to the viscose substrate using a spray technique. The tampon was sprayed with CS-lactic acid formulation (16% and 26%). Using a hot air chamber, the samples were dried. The treated materials were used to make tampons [39]. Superabsorbent Hydrogels (SAHs) made of CS and CS-derived polymers like CMCS are promising because they are biodegradable and biocompatible [65]. In order to create superabsorbent hydrogel, the native starch extracted from cassava underwent a chemical modification known as carboxymethylation. The native and carboxymethylated cassava starch were used to create the superabsorbent hydrogel, which absorbed water and saline, exceeding their dry weight more than 100 times. Since 70% of the hydrogels were biologically destroyed within 14 days, they were proved to have good biodegradability [58]. Cassava starch, CS, and AA synthesized superabsorbent hydrogel. Starch was extracted from the germinated sorghum by the alkali steeping process. The extracted starch was modified using graft polymerization of two polymers, AA and AM, onto starch to develop an absorbent core for personal care products. AA and AM were used as monomers, the cross-linker was methylene bisacrylamide, and the initiator was potassium persulphate to form the product. To enhance the water absorption capacity of the polymer, the formed product was subjected to saponification. To increase the porosity of the product, sodium bicarbonate was added to the reaction [61]. CS–silk dressings are a promising characteristic for implementation as a scaffold for delivering substances like exosomes. Oxidized hydroxyethyl starch hydrogel was synthesized with modified M-CMCS. This combination was used in synthesizing hydrogel network structure with excellent self-recoverable extensibility–compressibility, biocompatibility, biodegradability, and relatively good transparency properties. This composite structure reduced the wound fluid loss and consequently generated a moist environment, which resulted in faster wound healing [66]. Figure 4 illustrates the application of electrospun CS in wound healing. Electrospun fibre-based wound dressings made from a combination of CS, polyethylene oxide, and PVA fibres can be used. When these water-soluble copolymers are used, the stiff CS molecular chains can be entangled during electrospinning to create continuous nonwoven fibres with an average diameter of a few tenths to hundredths of a nanometer. Due to CS's stiff molecular structure, adding more of it to the fibres increases the bulk mechanical strength of fibre mats. The fibre mats' nanoscale pores encourage the permeability of the fibre dressings, which improves the exchange of oxygen as well as nutrients with the surrounding environment. Additionally, the porous fibre mat structure makes it easier for wound exudates to be absorbed while lowering the risk of bacterial infections. For applications in wound healing, CS-based electrospun fibres offer a multipurpose treatment capability through the inclusion of small molecule drugs and/or biological agents [67]. The electrospinning technology was used to create PVA/CS/starch nanofibrous mats for use as a wound dressing. The produced nanofibrous mats were characterised and evaluated for their potential as wound dressings after being cross-linked to improve the water resistance and also the rate of biodegradation. The effective management of wound exudates, and the appropriate porosity and balanced water absorption and water vapour transmission rates of the produced dressings show their capacity to provide a moist environment that is acceptable for the wound. The capacity of the manufactured wound dressing to shield the wound region from outside forces while the healing process is underway is confirmed by the nanofibrous dressing's suitable mechanical properties in both dry and wet states. Nanofibrous mats demonstrated remarkable anti-bacterial efficacy against both gram-positive and gram-negative microorganisms in anti-bacterial tests. Additionally, the developed nanofibrous mats' appropriate cytocompatibility and cell viability were demonstrated by an in vitro cytotoxicity test using the 3-(4,5-dimethylthiazolyl-2)-2, 5-diphenyltetrazolium bromide (MTT) assay. These findings, along with an in vitro wound healing analysis carried out using the scratch assay, confirmed the remarkable potential of the examined nanofibrous mats for use as wound dressings [68]. In order to create superabsorbent hydrogel, the native starch extracted from cassava underwent a chemical modification known as carboxymethylation. The native and carboxymethylated cassava starch were used to create the superabsorbent hydrogel, which absorbed water and saline much more than a hundred times their dry weight. Since 70% of the hydrogels were biologically destroyed within 14 days, they were proved to have good biodegradability. Hydrophilic groups, such as COO−, CHO, and OH, were added to the hydrogel due to the interaction between succinic anhydride and starch in the hydrogel production. The increased electrostatic repulsion strengthened the hydrogel's osmotic difference, which enhanced the hydrogels' absorbent properties. Although absorption capacity was lower at 0.9% than that found in water, commercial hydrogel (AQUA) had a better retention capacity because it could still hold onto 90% of the solvent after 48 hours. This indicated that the hydrogels made of carboxymethyl cassava starch had a strong water retention capacity in a 0.9% saline solution. The carboxymethylation caused some of the starch granules to break, indicating the high biodegradability of the carboxymethylated cassava starch [58]. Microwave irradiation was used to create CS-graft-poly(2-Acrylamido-2-methylpropane sulfonic acid (AMPS)-co-acrylic acid-co-acrylamide)/ground basalt from various materials like CS, basalt particles, AA, AM, AMPS, and Methylenebisacrylamide (MBA) and was used as a cross-linker. Interestingly, compared to the simple polymer, the basalt considerably increased the anti-bacterial [69]. Table 2 represents the various materials that have been used to date in the manufacturing and synthesis of sanitary products, including diapers, tampons, and sanitary napkins. For the first time, a novel CS/sponge CH-based membrane (CS/CH membrane) was made using the casting method. They obtained a chitinous network from the skeleton of the marine demosponge *Ianthella*, which was demineralised basta. The studies showed that the CS/CH membrane had good qualities. CH extracted from the sponge was added to the polymer matrix to provide the CS membrane very strong mechanical stability and electrochemical characteristics [70].

## 5. Hazards to Human Health

Personal hygiene and health care account for most SAP consumption worldwide than any other application. SAPs dumped in landfill cause pollution as they are not biodegradable. Diapers are unavoidable expenses in a parent's life as they are vital in a baby's life. As all parents seek comfort and ease, they gravitate towards diapers as they are easy to wear and dispose of and save much time. Each baby wears at least 6–8 diapers per day, then disposed of in the landfills, where they will take 100–500 years to decompose. The most alarming constituent of a diaper is sodium polyacrylate, which absorbs 100 times its weight but causes allergy, irritation, fever, infections, and vomiting. These products are even harder to degrade and thereby polluting the atmosphere. Various other chemicals, such as toluene, dipentene, and ethylbenzene, are all commonly found in diapers and are extremely harmful to children's health. The diaper components make it difficult for the microbes in the soil to initiate the decomposition process. Diapers rank third on the list of materials dumped in landfills. They not only contribute to pollution but also clog toilets and delay potty training. For all these reasons, the need to search for compostable diapers

Table 2: Materials that have been used to date for synthesizing sanitary products.

| Materials | Time line of usage | Applications for sanitation | Advantage | Anti-microbial activity against | Liquid retention/swell properties | References |
|---|---|---|---|---|---|---|
| Carboxymethylated cassava starch | 2019 | Sanitary napkins and disposable diapers | Good biodegradability, high water, and salt absorption capacity (hold solvent up to 48 hours) | | Strong water retention capacity in 0.9% saline solution | [58] |
| Cellulose acetate and lignin copper complexes of *N*-vanillidene-2-amino-thiazole Schiff base derivatives | 2022 | Hygiene products | Biocompatible, easy processability, low price, and higher water retention under-load when compared to the traditional cellulosic wood pulp, they have a greater surface area and high porosity, anti-microbial activity | *Acinetobacter baumannii*, *Staphylococcus epidermidis*, and *Streptococcus faecalis* | 4200% increase in water absorption | [48] |
| Chitosan, citric acid, and urea | 2018 | Diapers | Biodegradable, biocompatible, bioactivity, fungi-static, bacterio- static, and haemostatic. | | | [55] |
| Sodium carboxymethyl cellulose and starch | 2020 | Female sanitary napkins | Polyacrylate-free, biodegradable, and superabsorbent | | | [59] |
| Cross-linked superabsorbent natural hydrogel from cellulose–chitosan | 2018 | Use in diapers, feminine hygiene items, wound dressings, soaking pads for meat, wiping papers, and agricultural applications | Minimal environmental impact as the process only produces water as a by-product | | The water retention value of the novel hydrogels (85 g/g) in saline water was twice as high as that of commercial gels (40–50 g/g). | [47] |
| Chitosan-based novel superabsorbent hydrogel | 2011 | | It is inexpensive, biocompatible, and readily available | | The higher water holding capacity of DHPC-GMA-gPAAm, the highest swelling percentages of 1897.2%, 1507.1%, and 1432.2% | [20] |
| Chitosan | 2011 | | Biocompatibility so no harmful effects, can be thus used during pregnancy as well | | | [39] |
| Silver nanoparticles/chitosan/polyvinyl alcohol/polyethylene glycol hydrogel nanocomposite | 2016 | Nasal tamponstable | Anti-microbial<br>Haemostatic activity, water retention, wound healing, biopolymers, biocompatible, non-toxic, and swelling | *Staphylococcus aureus* | | [24] |
| Cellulosic polymers, sodium alginate, CMC, and non-woven fabrics | 2021 | | Biodegradability, environment-friendly, and more water uptake | The anti-bacterial activity was checked and showed that the neem leaf effectively reduced the growth of | Absorption capacity 63.20g | [60] |

Table 2: Continued.

| Materials | Time line of usage | Applications for sanitation | Advantage | Anti-microbial activity against | Liquid retention/swell properties | References |
|---|---|---|---|---|---|---|
| | | | | *S. aureus and Escherichia coli* | | |
| Waste sorghum grains | 2018 | Personal care products—sanitary pad and baby diaper | Swelling power was increased | | Water absorption capacity (380.9 g/g) | [61] |

is more than ever [71]. The viscose crayon in the tampon contains dioxin, which is very harmful to the human body These tampons also contain very high levels of toxic shock syndrome toxin when compared to the cotton tampons used previously [24]. Diaper dermatitis is one of the most prevalent problems with wearing a diaper. Only barrier creams and anti-fungal agents are available for treatment. However, using biobased polymers as the top sheet in diaper construction can lead to healthy as well as economic diapers, which are biodegradable [72]. Conventional plastics and materials derived from plastic that contains bisphenol A, which had shown to reduce fertility, raise the risk of miscarriage in expectant mothers, and even premature birth [73]. Radioactive metal ions, like $Cs^+$, ${Sr_2}^+$, and ${Co_2}^+$, released from nuclear power plants are lethal to the environment and human health. The effective removals of these ions via hydrogels have recently gained attention. Superabsorbent composites like CS, guar gum, starch, sodium alginate, and CMC can be used as sorbent material [74].

Superabsorbents are made of polysaccharides. They have prospective applications in various industries, like biomedicine, sanitation, agriculture, and water treatment. They are considered good materials due to their high absorption capacities, but growing environmental worries about toxicity in waste are forcing manufacturers to choose more natural sources [30]. The usage of polysaccharides in cosmetic items is expanding, along with manufacturers' focus on environmentally friendly materials. Hydrogels made of cellulose are biocompatible and biodegradable, and they have a bright future in a variety of industrial applications, including hygienic goods, particularly when it comes to environmental concerns. Cross-linked cellulose–CS hydrogels were potential "green" superabsorbent due to their biodegradable makeup and environmentally friendly cross-linking method [48]. Recyclable films have been synthesized using CS to remove ketoprofen from water. The film produced was recyclable and could be used for consecutives cycles by extending CS lifetime [75].

## 6. Anti-Microbial Activity of CS

Methylation of CS leads to a positively charged salt of trimethyl chitosan . This TMC has positively charged groups that react with the negative microbe cell wall. CS adsorbs the microbial cell wall and destroys the plasma membrane, due to which the cytoplasm leaks leading to cell death. CS varnish was produced to avoid an accumulation of dental plaques. It effectively inhibited plaque formation by forming flocs as the bridges (bridges formed between positively charged chains that attach to the microbial wall) become effective, thus inhibiting *S. mutans*. The activity of CS was compared to chlorhexidine fluoride varnish, which is known as a chemotherapeutic agent and was found to be similar [76]. The electrostatic interaction between the positively charged CS molecules and the microbe surface negatively charged is the most widely acknowledged mechanism for microbial inhibitions [77].

The combination of CS, Citronella essential oil (CEO), Zinc oxide (ZnO), and AgNPs clearly showed a robust anti-bacterial activity, as shown by the results of the anti-microbial assay [49]. Tampons for gynecological therapy with CS nanopolymers were created and described as anti-microbial medicinal textiles [78]. By covalently bonding to antibiotics or anti-fungal drugs, CS's anti-microbial activity could be tailored and improved to treat nosocomial infections [33]. CS being the second most abundant polymer and being anti-microbial is a strong candidate as an alternative. The coating ability of CS is also reported making it a promising alternative. The citric acid and CS-treated carrots displayed a reduction in microbial activity compared to the control, signifying the pronounced bactericidal effect of CS [36]. The anti-microbial activity of the natural pure CS was evaluated using the colorimetric microdilution test. The Minimum Inhibitory Concentration (MIC) values found for CS were found out to be 0.62 mg/mL for *E. coli* and 0.31 mg/mL for *P. aeruginosa* and *S. aureus* [34]. Copper complexes of *N*-vanillidene-2-amino-thiazole Schiff base derivatives were synthesized and added to the blend of CA and lignin. This copper complex was screened for its anti-microbial activity against, *S. faecalis*, *Acinetobacter baumannii*, and *S. epidermidis* [36]. CS, the second most abundant polymer and antimicrobial, is a strong candidate as an alternative [37]. Food packaging can be enhanced by incorporating CS as it can increase the anti-microbial efficacy. Film packaging materials are being developed using CS with natural polysaccharides [38]. Cellulose materials functionalized with CS can be used in gynecological applications as they efficiently inhibit pathogenic microbes, do not alter the resident flora, and display no cytotoxic effect [40]. Trimethyl chitosan chloride is an essential derivative of CS that is synthesized due to its enhanced absorption and anti-bacterial activity [41]. Using CS in textiles provided various functionalities, such as anti-microbial, cosmetic, medical, thermoregulating, ultraviolet-protective, and insect-repellent textiles

[43]. CS-coated surgical materials are cheap and provide anti-microbial activity, which has tremendously helped surgeries [79]. It showed that the lowest molecular weight CS inhibited the microbes readily. With an increase in molecular weight, the inhibition of bacteria was increased. CS-based textiles have different properties, such as aroma finish, thermal comfort, insect repellence, and anti-microbial activity [45]. Adding metal ions into CS will increase their anti-microbial potency even further, as they already have a larger surface area and excellent chelating ability. Wound management is another field where the ultimate goal is healing without microbial infection. For this purpose, natural product anti-microbial agents, such as tea tree oil CS and aloe vera can be used in wound dressings [80].

## 7. Conclusion

CS is a polysaccharide mostly obtained from CH, the second most abundant polymer, mainly found in the exoskeleton of most crustaceans, cuticles of insects, and fungal cell walls. CS, upon modification, has a wide array of applications, such as a carrier in the delivery of drugs, in cosmetics, coatings, food packaging, food preservation, diapers, and feminine hygiene items, wound dressings, soaking pads for meat, wiping papers, and agricultural applications. CS is a linear polysaccharide found in nature that contains hydroxyl and amino groups in its backbone. Using CS as a natural alternative in superabsorbents via different methods is very economical as it is abundant in nature. Unlike commercially available diapers, which do not degrade and accumulate in the environment, becoming a pollutant, CS is readily biodegradable. Optimization of CS is essential before using it in any application. Pure CS only has limited uses, so modification of CS, like cross-linking, is required before application. CS has excellent anti-bacterial properties as it destroys the plasma membrane of various bacteria, leading to lysis. The anti-microbial activity, super absorbency, and degradability are some of the properties of CS that make it an ideal candidate for sanitary pads, diapers, and incontinence pads. Various applications of CS include drug delivery, food packaging, sanitary products, wound dressings, and implants. CS itself or combined with other biopolymers like cellulose and alginate has diverse applications in textile industries, and shortly because of the increasing shift towards bio-based diapers, people will tend to prefer products made up of biobased materials, such as CS, which is easily available naturally and has greater benefits compared to the commercial non-biodegradable products available in the market. With increased environmental protection demand, CS serves as a quintessential source. This study indicates further scope to explore the functionality of CS and how mankind can exploit this resource due to its renewability. To conclude, CS as a biomaterial has potential applications in manufacturing diapers and female hygiene products, such as tampons and sanitary napkins.

## 8. Future Directions

Non-biodegradable synthetic diapers will soon be exchanged with biodegradable materials derived from various natural resources. Eventually, biodegradable sanitary products will constitute a niche market that will be the future. Multidisciplinary research by microbiologists, environmentalist, and polymer technologists are required to implement and commercialize biodegradable SAPs successfully. Assuredly, biodegradable SAPs offer an alluring route to environmental waste management. CS has very limited applications and poor mechanical properties in its pure form. However, modifications have proven to have made CS work for various domains. More research is required along the area of recyclability of CS sanitary products. If the tampons and pads made of CS are made recyclable then it will also boost the area of environmental protection.

## Data Availability

All the data is in the manuscript.

## Conflicts of Interest

The author(s) declare(s) that they have no conflicts of interest.

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