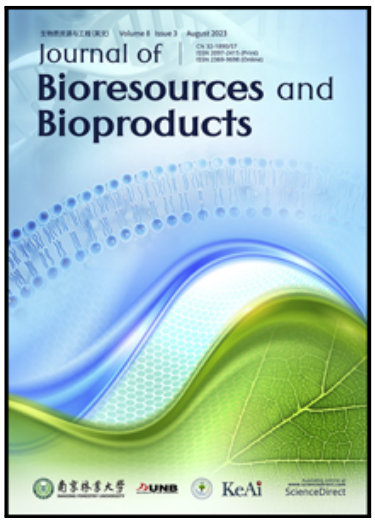


Advances in Manufacturing Sustainable Textile Fibers from Chitin and its Derivatives: Spinning Methods, Fiber Functional Properties, Biodegradability, and Environmental Impacts

Mohammad Mahbubul Hassan

PII: S2369-9698(26)00072-1
DOI: https://doi.org/10.1016/j.jobab.2026.100300
Reference: JOBAB 100300

To appear in: *Journal of Bioresources and Bioproducts*

Received date: 25 June 2026
Revised date: 20 August 2026
Accepted date: 24 August 2026

Please cite this article as: Mohammad Mahbubul Hassan , Advances in Manufacturing Sustainable Textile Fibers from Chitin and its Derivatives: Spinning Methods, Fiber Functional Properties, Biodegradability, and Environmental Impacts, *Journal of Bioresources and Bioproducts* (2026), doi: https://doi.org/10.1016/j.jobab.2026.100300

Advances in Manufacturing Sustainable Textile Fibers from Chitin and its Derivatives: Spinning Methods, Fiber Functional Properties, Biodegradability, and Environmental Impacts*

Mohammad Mahbubul Hassan

Fashion, Textiles and Technology Institute, University of the Arts London, London E20 2AR, United Kingdom

Received 25 June 2026

Received in revised form 20 August 2026

Accepted 24 August 2026

Abstract: Most of the current textiles are made from non-renewable, non-biodegradable synthetic fibers that are a source of microplastic pollution. The alternative biodegradable natural fibers have not only limited production but also have high energy and water usage along with high carbon footprints. Chitin has immense possibilities to replace non-biodegradable synthetic polymers for textile fiber manufacturing because of its abundance, biodegradability, and many beneficial functional properties. Despite its abundance, its utilization in textile fiber manufacturing is limited because of its insolubility and performance issues. Spinning of fibers from chitin derivatives for textile production was mainly studied by wet and dry-jet wet spinning methods using a range of solvents including ionic liquids, spinning dope additives (other polymers, nanoparticles), and various coagulation baths that considerably enhanced fiber performance and functionalities. Recent advancements enabled manufacturing fibers by gel spinning directly from chitin without any derivatization, which produced fibers with strength comparable to several natural fibers. This review discusses chitin and its derivatives as fiber-forming polymers, spinning methods, various solvents used, spinning methods, fiber crosslinking, and spinning dope additives to enhance the mechanical and functional properties of the resultant fibers. The discussion also includes the toxicity and biodegradation of chitin fiber, carbon footprints, and future directions in advancing its application towards sustainable fiber production. The key limitation of the review article is the

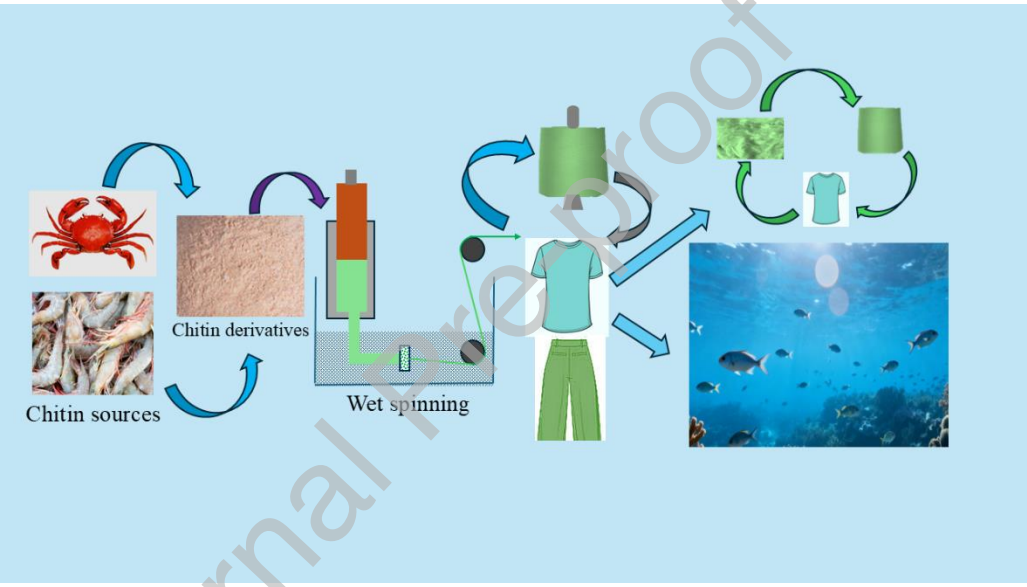
* Corresponding author.

E-mail address: mahbubul.hassan@arts.ac.uk (Mohammad Mahbubul Hassan)

consideration of only published peer-reviewed journal articles but no patent specifications. A limited number of published articles discussed the structure-property relationship of fibers produced from chitin and its derivatives. The true comparison of various performances of fibers produced by various methods was difficult due to different conditions used by different research groups. It is possible to manufacture textile fibers with strength comparable to many natural fibers by selecting the right source of chitin and its derivatives.

Keywords: chitin and its derivatives; sustainable fiber-forming polymer; fiber spinning method; mechanical and functional properties; toxicity and biodegradation; environmental footprint

Graphical Abstract:



1. Introduction

Clothing is integral to human life, which protects us from various adversities, such as dirt, microbial attack, heat, cold, and light. The global production of textile fibers reached ~132 million tons in 2024 (Materials Market Report, 2025. Textile Exchange. Available at: https,//textileexchange.org/knowledge-center/reports/materials-market-report-2025/ accessed on 14 February 2026), and ~77% of them were made from petroleum-based polymers (Frazier et al., 2024). Polyester has been the most widely used fiber in textile manufacturing for over 80 years for its low cost and many beneficial properties, including high strength and longevity, easy dyeability, and good hydrophobicity. Textiles made from non-biodegradable synthetic fibers, like polyester, are a potential source for microplastic (MP) release to the environment, which is now a global environmental issue. Other popular synthetic fibers include nylon, acrylic, and polypropylene, and textiles made from these fibers can also release MPs during their laundering and after

end-of-life disposal (Cai et al., 2021). Many synthetic post-consumer and unused or unsold textiles end up in landfills or are incinerated, polluting soils, water, and air (Geyer et al., 2017). The fast fashion trend exacerbates this issue, as many low-cost and low-quality products made of polyester fibers are more frequently discarded compared to the higher-quality items (Niinimäki et al., 2020), and they shed high amounts of fiber fragments during their first few washes (Yang et al., 2021). A range of biodegradable polyester fibers (e.g., polylactic acid and polyhydroxyalkanoate) have been developed, but in terms of performance they are not at all comparable to polyester and polyamide fibers, and they also have many processing difficulties and performance and cost issues. Polylactic acid (PLA) films biodegrade very slowly only at industrial thermophilic composting conditions (Kalita et al., 2019). Although poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) copolymer has better biodegradability than PLA, PHBV is quite expensive, and its biodegradation in soil takes several months to a couple of years, depending on thickness (Lyshtva et al., 2024). Therefore, their use in textile manufacturing is very limited.

It is necessary to mitigate microplastic release from textiles and decarbonize textile fiber manufacturing by replacing synthetic fibers with biodegradable biobased fibers. However, increasing the production of natural fibers will require vast farmlands, threatening global food security. A range of biobased feedstocks, including agricultural waste, such as pineapple leaf (Chaves et al., 2024), banana pith (Ruangnarong et al., 2024), straw, and bagasse (Costa et al., 2013), and other renewable biomasses, such as fungi and marine algae (Fujiwara et al., 2020), have been studied for fiber production. However, they can only meet a small fraction of the demand, mostly because of their non-abundance and difficulty in processing. Most of the natural fibers are weak, and fabrics made from them are less durable than fabrics made from synthetics. In this context, abundantly available biodegradable chitin extracted from waste biomass with a global production of ~1 000 billion tons/annum (Hahn et al., 2020) is highly attractive as a feedstock for fiber manufacturing. Chitin is biodegradable, biocompatible, and non-toxic, along with many beneficial functional properties. However, chitin is insoluble in water and most of the solvents, limiting its application, while its water-soluble deacetylated derivative, chitosan (CS), has found applications in fiber manufacturing (Abdelgawad et al., 2014), textile dyeing and finishing (Hassan, 2015; Hassan and Hudson, 2026), dyehouse effluent treatment (Hassan and Carr, 2018), and other applications (Edo et al., 2024).

Several review articles have been published on chitosan fibers, mainly covering nanofiber formation for wider application, such as wound dressings and biomedical devices (Rathke and Hudson, 1994; Pillai et al., 2009; Wang et al., 2025), other than textile manufacturing. Another article reviewed various chemical modifications studied for introducing various functionalities to chitosan fibers for diverse applications (Kartik et al., 2025). Recently, a review article outlined the application of chitin and its derivatives to various treatments and functional finishing of textiles (Hassan and Hudson, 2026). However, none of the articles reviewed the manufacturing of textile fibers directly from chitin and chitin fibrils, chitin

derivatives, and various strength enhancement strategies studied to enhance their strength, stability, and functional properties. Additionally, no article compared the mechanical and functional properties of fibers made from various chitin derivatives alone and with other additives produced by various spinning methods, and carbon footprints with other natural fibers.

Advancements in spinning methods, such as gel and dry-jet wet spinning, and novel chitin solvents such as ILs, have made a huge breakthrough in enhancing the strength of chitin fibers and have enabled the manufacturing of textile fibers directly from chitin (Wang et al., 2020; Chen et al., 2022a; Feng et al., 2025). Fibers made from chitin and its derivatives alone or with other additives show fiber properties comparable to many natural fibers. Currently, the focus has shifted toward solving processing challenges and improving the strength of fibers through utilizing green chemistry, including the use of ionic liquids (ILs) as a chitin solvent, facilitating its conversion into high-performance sustainable fibers. This review article offers an overview of the feasibility of chitin as a fiber-forming polymer for the manufacturing of textile fibers, chitin modifications for textile fiber manufacturing, spinning processes, and mechanical and functional properties of the produced fibers. Several functional properties, biodegradation, and carbon footprints of fibers produced from chitin and its derivatives are also discussed.

2. Chitin Extraction and Derivatization

Chitin can be extracted from several biological sources, including marine crustaceans (e.g., shrimp, squid pen, and crabs), insects (e.g., cockroaches, beetles) (Ma et al., 2015a), and fungi (Arbia et al., 2013; Crini, 2019). The utilization of crustacean waste biomass for chitin production is highly advantageous, as they are usually dumped back into the ocean, causing severe marine pollution (Tacon, 2018). The exoskeleton of crustaceans is rigid and consists of a three-layered cuticle comprised mostly of chitin and proteins, inorganic salts, pigments, and lipids (Amiri et al., 2022). In insects, chitin is the primary structural component of the exoskeleton and other cuticular structures, providing strength, rigidity, a waterproof barrier, and protection to internal tissues (Sieber et al., 2018). Insect growth requires the repetitive synthesis and degradation of chitinous cuticles through a molting process. The insects studied for chitin production are cicadas, silkworms, and honeybees (Draczynski, 2008; Battampara et al., 2020), and they often provide higher yields compared to marine crustaceans. Chitin can also be biosynthesized from glucose or trehalose into uridine diphosphate-N-acetylglucosamine (UDP-GlcNAc) via fermentation, which can be converted into chitin via various enzymatic processes (Chen et al., 2022b).

2.1. Extraction processes

The extraction process varies depending on the feedstocks, such as crustaceans, insects, fungi, or biochemically produced chitin. Chitin is primarily present in the inner layers of shells wrapped in proteins, while the outer layer is composed of calcium carbonate and proteins. The traditional chitin extraction

process is divided into pre-treatment, demineralization, decolorization, and deproteinization steps. The biomass is washed and powdered, and the mineral components (e.g., calcium carbonate) are removed by dissolving them in a strong acid solution. They are then decolorized by oxidation treatments with hydrogen peroxide or sodium hypochlorite, followed by treatment with a strong alkali to dissolve proteins to isolate chitin. As strong alkali can degrade chitin, various enzymes, such as aspartic protease (Deng et al., 2020), neutral protease in combination with microwave heating (Dong et al., 2023), and protease from *Streptomyces griseus* (Hongkulsup et al., 2016), were studied for the selective dissolution of proteins. Recently, ILs were also studied for the direct extraction of chitin by a single step by dissolving crustacean shells in them and then precipitating and insolubilizing the chitin with an antisolvent. The ILs can also be used as a solvent for chitin and its derivatives, as they can dissolve chitin via the disruption of the hydrogen bonding between the amide and hydroxyl groups of chitin. The addition of urea or thiourea to ILs enhances their chitin-dissolving capability (Zhong et al., 2020). However, the extraction of chitin from marine biomass presents several challenges, such as low chitin content and the need for extensive purification, increasing the cost of chitin. Insects offer a promising and sustainable alternative that can help meet the growing demand for chitin (Rehman et al., 2023).

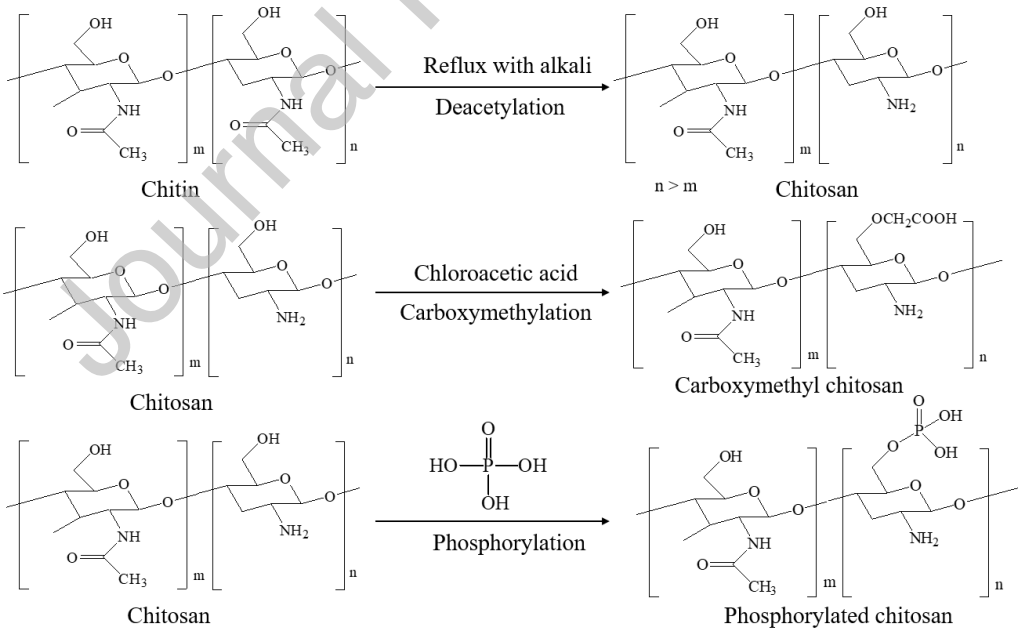
2.2. Derivatization of chitin

Chitin is chemically modified to enhance its water-solubility for spinning into fiber and also to enhance functional properties. The simplest derivative of chitin is CS, which is soluble in 2% acetic acid (AA) solution and has been mostly studied for fiber production. It is produced by breaking the acetamide ester linkage of chitin through deacetylation, converting the N-acetyl group into a primary amine. Deacetylation is conducted at acidic or alkaline reflux conditions under an inert atmosphere, but the alkaline method is preferred due to the acidolysis of polysaccharides occurring in acidic conditions, since acids can damage glycosidic bonds, leading to polymer chain breakdown (Rahayu et al., 2022). Purified chitin is typically dispersed in a strong sodium hydroxide solution and heated at 120 □ under an inert atmosphere for varying durations, depending on the required degree of deacetylation (DD) (Galeda et al., 2008). The molecular weight (MW), tensile strength, and thermal stability of chitin decrease with an increase in DD due to depolymerization (Másson, 2024). To classify the deacetylated chitin as CS, the DD must be at least 50%.

Many derivatives of chitin are reported in published literature (El-Tahlawy et al., 2007; Hassan, 2015; Bao et al., 2020; Zhou et al., 2023), but CS, carboxymethyl chitosan (CMCS), iminochitosan (iCS), butyryl iminochitosan (BICS), and imidochitosan (IdCS) are only studied for fiber production. For synthesizing various derivatives, chitin is partially deacetylated to CS, transforming N-acetyl-D-glucosamine units into D-glucosamine units containing a free amine group ($–NH_2$). The functional groups ($–NH_2$ or $–CH_2OH$) of CS are utilized to modify CS into various derivatives. Figure 1 shows the conversion of chitin to CS, CMCS, phosphorylated chitosan (pCS), iCS, and BICS. CS is produced by the partial or full deacetylation

of chitin in a strong sodium hydroxide solution by heating under an inert atmosphere. The solubility in 1%–2% aqueous acetic acid solution increases with an increase in DD, but it is still insoluble in alkaline conditions. The CMCS can be prepared from chitin by partial deacetylation and then reacting it with chloroacetic acid under alkaline conditions, which converts $–CH_2OH$ groups of CS into carboxylic acid groups ($–CH_2COOH$), forming water-soluble amphoteric CMCS containing both cationic amino and anionic carboxylic acid groups. The pCS is produced by reacting CS with a phosphorylating agent, such as phosphoric acid, phosphorus pentoxide, or phosphorus trichloride, which introduces phosphonic acid groups in CS (Jayakumar et al., 2008).

The iCS is prepared to protect its free amino groups from acylation and also to decrease the solubility of CS in water by the introduction of a hydrophobic group. Hydrolyzed CS reacts with salicylaldehyde at room temperature for 6 h to convert CS into iCS. The modified CS is filtered, washed with distilled water, and then purified by Soxhlet extraction with methanol for 6 h. The iCS can be further modified by O-acylation by reacting iCS with different acid chlorides in the presence of a catalyst (pyridine, triethylamine, or triethanolamine) using dimethylformamide (DMF) as a solvent (El-Tahlawy et al., 2007). For example, BICS can be synthesized by reacting iCS with isobutyryl chloride (iBC) at 0 □ for 3 h in the presence of pyridine using DMF as a solvent. The end product is purified by initially washing with water to remove pyridine salt and then with methanol by Soxhlet extraction for 24 h.



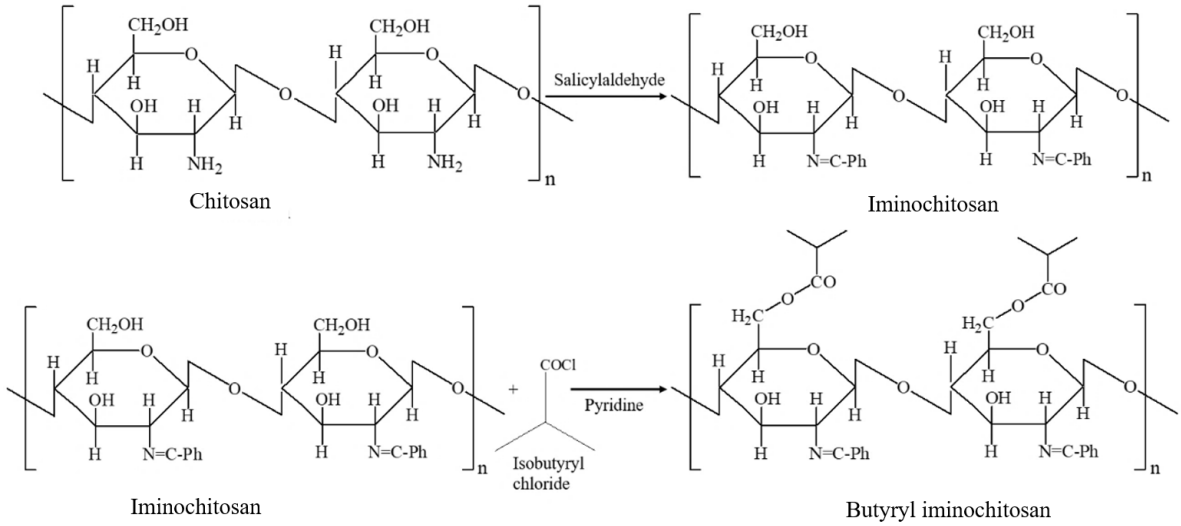


Fig. 1 Schemes showing synthesis of various derivatives of chitin, such as carboxymethyl chitosan, phosphorylated chitosan and iminochitosan and butyryl iminochitosan (El-Tahlawy et al., 2007, reproduced with copyright permission from John Wiley and Sons).

The modification of CS with various chemical compounds, such as coumarin-3-carboxylic acid (CCA) producing CCA-m-CS, and grafting with polyethylene glycol monomethyl ether (mPEG) producing CS-g-mPEG, was explored to enhance the physicochemical properties of the resultant modified CS fibers (Bao et al., 2020; Zhou et al., 2023) as illustrated in Fig. 2. The CCA was bonded to the amino groups of CS by using N,N'-dicyclohexylcarbodiimide (DCC) crosslinker, which is a widely used coupling agent for the binding the amino group containing compound to the carboxylic acid group containing compound via formation of amide bonds.

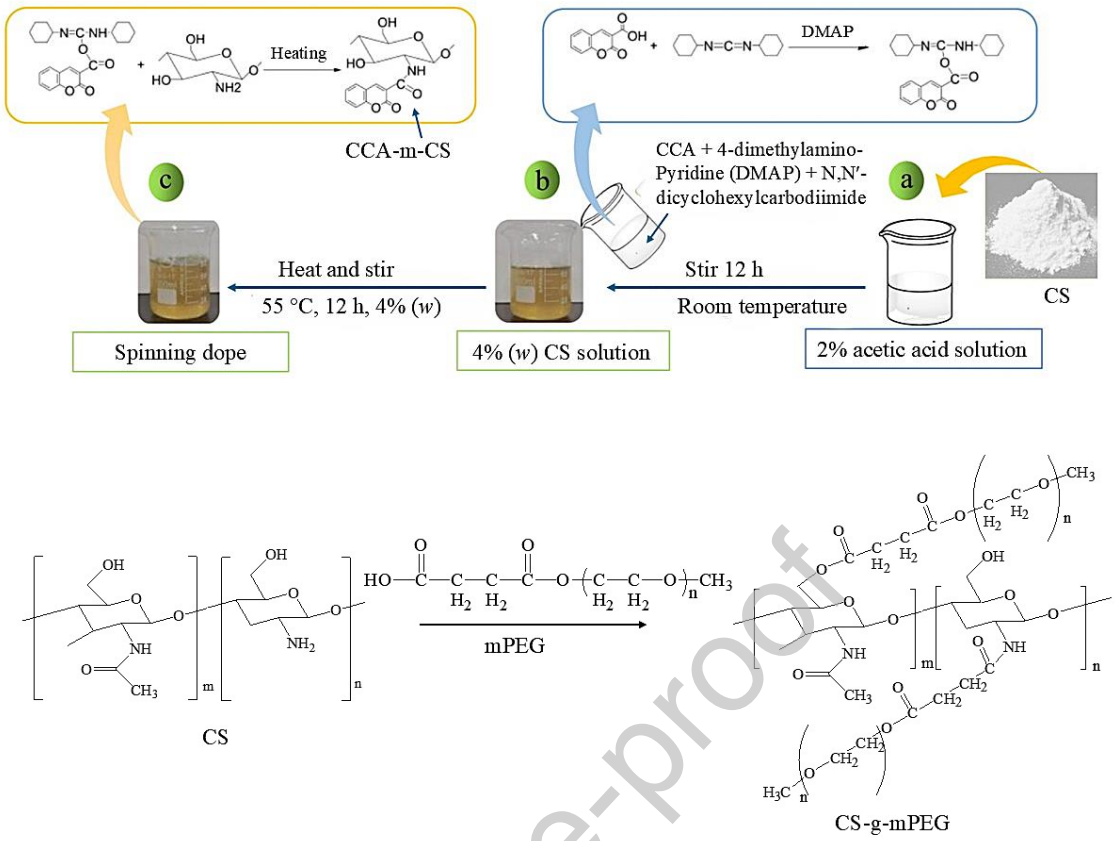


Fig. 2 Schematic diagrams of synthesis of (top) chitosan (CS) modified with coumarin-3-carboxylic acid (CCA) (CCA-m-CS) (Zhou et al., 2023, reproduced with permission from Elsevier), and (bottom) CS grafted polyethylene glycol monomethyl ether (mPEG) (CS-g-mPEG) fiber.

Chitin fibers have several advantages over other natural fibers. For example, fibers made from chitin and its hydrophobic derivatives can be dyed with disperse dyes like cellulose acetate (CA) fibers due to the presence of hydrophobic acetyl groups in chitin and therefore may show some level of water repellency. Fibers derived from chitosan and other cationic derivatives can be dyed with acid and reactive dyes without using any electrolytes, producing cleaner effluent. However, fibers made from chitin (especially chitosan and other hydrophilic derivatives) by wet spinning were quite weak, had limited durability, and were unsuitable for textile production. Because of their hemostatic, analgesic, antimicrobial, and anti-inflammatory properties, wet-spun chitosan fibers were initially studied for sutures (Tachibana et al., 1988; Shao et al., 2016) and nonwoven fabric-based wound care material applications (Masood et al., 2017; Qian, 2011).

3. Manufacturing Fibers

For spinning of fibers, chitin and its derivatives are initially dissolved in an appropriate solvent, forming a viscous solution, and then fibers are made by forcing this solution through a spinneret.

3.1. Solvents for chitin and its derivatives

Initial studies used a 2% aqueous solution of AA as a solvent for spinning fibers from chitin and its derivatives. Other than AA, lactic acid (LA), adipic acid (AdA) (Mohammadkhani et al., 2021), 2% lithium hydroxide (LiOH) + 6.0% urea (Li et al., 2012a), and also aqueous AA/methanol (Judawisastra et al., 2015) were studied for this purpose. The solubility of chitin in AA solution decreases with a decrease in the degree of deacetylation of chitin, and pure chitin is completely insoluble in it. The ILs formed by mixing two opposite ionic compounds, such as organic heterocyclic cations and organic or inorganic anions, are uniquely capable of dissolving raw, highly crystalline chitin, enabling spinning of fibers directly from chitin. The ILs have good solvation power, low toxicity, negligible vapor pressure, and potential for recycling (Hassan, 2025). The ILs studied are glycine hydrochloride ([Gly]HCl) (Li et al., 2012b; Ma et al., 2015b), N-methylimidazole (Xie et al., 2006), [Gly]HCl/N-methylimidazole 1-chlorobutane ([Bmim]Cl) (Ma et al., 2013), 1-butyl-3-methylimidazolium acetate ([Bmim]Ac) (Barber et al., 2014; Kuznik et al., 2022), and 1-ethyl-3-methylimidazolium propionate ([C_2C_1Im][OPr]) (Mundsinger et al., 2015). The spinning of fibers from chitin and its derivatives was studied mainly by four methods, as mentioned below:

3.2. Fiber spinning

3.2.1. Wet-spinning

Wet spinning is the most studied spinning method to produce fibers from chitin and its derivatives. A schematic diagram illustrating wet spinning for chitin/CS fiber manufacturing is presented in Fig. 3 (top). Typically, chitin and its derivatives (e.g., CS) are dissolved in a solvent and then spun into continuous multi-fiber filaments by extruding into a coagulation bath through a spinneret with multiple holes. The coagulation bath is used to solidify the dissolved polymer into a solid fiber in a non-solvent. In the next baths, the fibers are washed to remove any residual coagulating salts and alkali. Finally, the fibers are dried and drawn to enhance their crystalline structure and strength. For example, wet spinning of CS fibers was studied by dissolving CS in a 2% AA solution and then extruding through a spinneret into a coagulation bath of sodium hydroxide (NaOH) and sodium sulfate (Na_2SO_4) (East and Qin, 1993). Not only fiber formation from crustaceans, but also chitin formed by fungi was also studied by this spinning method (Svensson et al., 2021; Perrin et al., 2022; Wijayarathna et al., 2024). Initial studies used an aqueous coagulation bath containing 5% sodium hydroxide (Barber et al., 2014), 10% NaOH (Lee, 2003), 10% NaOH + 30% Na_2SO_4 (Hirano, 2001), a 50/50 mixture of 10% NaOH + ethanol (Dresvyanina et al., 2013; Mohammadkhani et al., 2021), and 10% aqueous NaOH (Lee, 2003), as a nonsolvent. The production of chitin fibers from β-chitin nanofibrils (ChNF) was also studied by wet spinning using a syringe pump, and

the fibers were extruded into an aqueous NaOH coagulation bath (Chen et al., 2022a). The regenerated wet-spun fibers produced from chitin and its derivatives usually exhibit poor wet strength. The fibers made from CS dissolved in AA by wet spinning are mostly amorphous, and therefore they are weak, but wet spinning remains the most popular method because it permits manufacturing of fibers from heat-sensitive polymers that break down or degrade before melting.

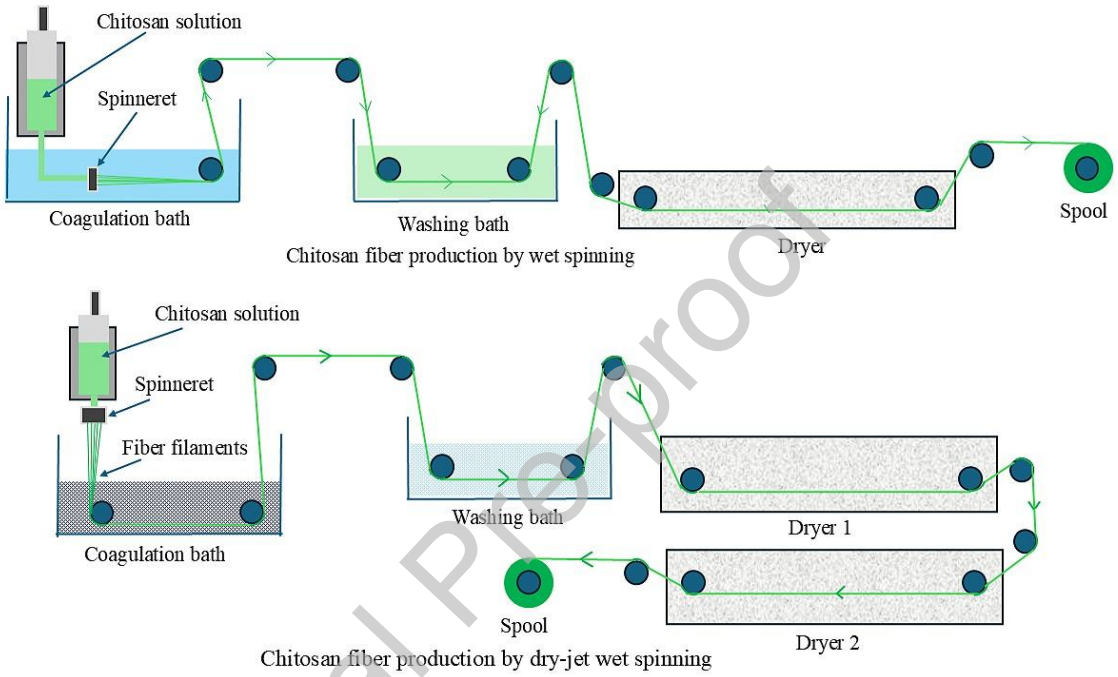


Fig. 3 Schematic diagram of wet spinning (top) and dry-jet wet spinning (bottom) of chitosan (CS) fibers

3.2.2. Dry-jet wet spinning

To improve the fiber strength, dry-jet wet spinning was studied, which is a hybrid method that combines elements of both dry and wet spinning. In this process, the spinning dope is extruded through a spinneret into multifilament, passing through an air gap before entering the coagulation bath as illustrated in Fig. 3 (bottom), allowing partial drying of fibers before entering the coagulation bath, producing stronger fibers with a higher modulus due to the partial evaporation of the solvent before the orientation and solidification of fibers occur in the coagulation bath. It combines the high speed and stretchability of dry spinning with the effective solidification control of wet spinning. This lets makers stretch the polymer stream in an air gap before it enters a liquid bath, producing high-strength fibers. Fibers made from BICS mixed with CA using N-Methyl-2-pyrrolidone (NMP) as a solvent, using a coagulation bath containing sodium methylate and methanol, had a higher strength and were also uniform in size (El-Tahlawy et al., 2007). Fibers

produced from a 50/50 mixture of CS and cellulose (Cel) dissolved in $[C_2C_1Im][OPr]$ IL by this spinning method were quite strong (Ota et al., 2021).

3.2.3. Gel spinning

Gel spinning is mostly used for the spinning of high strength and high-modulus fibers from ultra-high molecular weight polymers. Gel spinning can be like wet-spinning or dry-jet spinning except that the polymer solution (spinning dope) is converted into a highly viscous gel, and the spinning machine has a strong pump to force the gel through a spinneret to create fibers. Gel spinning was mainly studied for the production of fibers from pure chitin. The fibers made by dissolving high MW chitin in an aqueous solution containing 2% AA and then extruding into warm air to make filaments, followed by passing through a coagulation bath containing gaseous ammonia, produced fibers with better strength compared to wet/dry-jet spinning (Notin et al., 2006). Gel spinning was also successfully utilized to produce cellulose nanofibers (CelNF)-filled chitin fiber (Marquez-Bravo et al., 2021). Gel spinning creates super-strong, lightweight fibers like ultra-high-molecular-weight polyethylene (UHMWPE) and aramid by keeping long polymer chains bound in a gel state, allowing intense stretching that aligns molecules tightly with highly ordered molecular alignment for maximum tensile strength. The key advantage of this process is that high-strength fibers can be directly manufactured from chitin without any derivatization, reducing the cost of fiber production.

3.2.4. Spinning nanofibers

Nanofibers from chitin and its derivatives are produced as nanofibrous nonwoven mats, not for textile fabric manufacturing but for textile finishing, creating breathable, high-surface-area membranes on textiles to enhance or add functional properties like waterproofing, antimicrobial protection, and thermal regulation without adding heavy bulk. The nanofiber manufacturing techniques are also used to create medical textiles (e.g., medical masks, wound dressings). For the spinning of nanofibers, electrospinning, centrifugal, and electro-centrifugal spinning methods have been studied. A graphical representation of the mechanism of electrospinning of polymeric nanofibers is shown in Fig. 4. The nanofiber formation process by electrospinning is an electrohydrodynamic process, in which a liquid droplet is electrified to generate a jet of polymer solution, followed by stretching and elongation to form nanofibers (Pervez et al., 2024). Upon electrification, the electrostatic repulsion among the surface charges due to the disparity in electrical potential between the spinneret tip and the collector deforms the droplet into a Taylor cone, from which a charged jet of polymer solution is ejected. It initially extends in a straight line and then undergoes strong turbulent motions because of bending instabilities. The produced nanofibers are deposited on the collector.

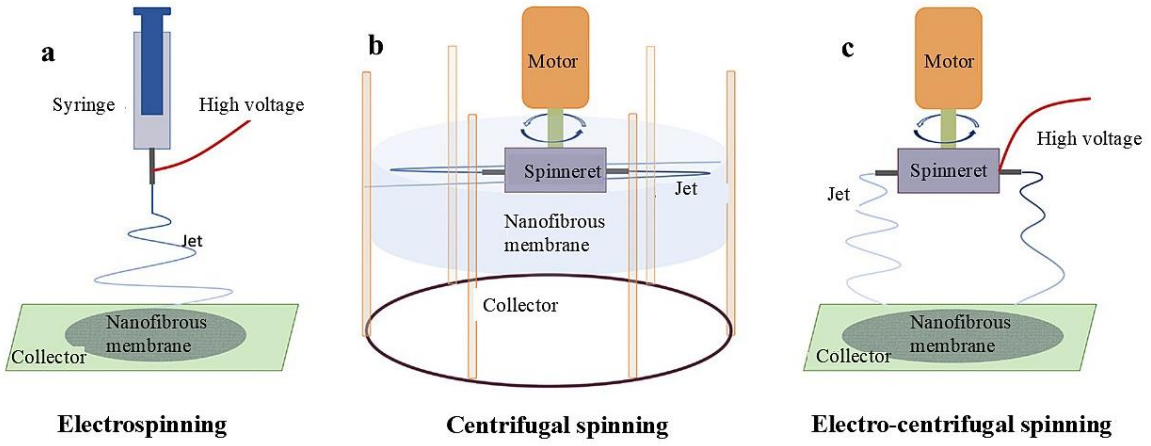


Fig. 4 The basic principle of various nanofiber spinning methods illustrated by a schematic diagram (Xu et al., 2023).

Centrifugal spinning uses centrifugal force instead of a high-voltage electrostatic force used in electrospinning to eject polymer jets from a rotating head with spinnerets, forming fine fibers, as illustrated in Fig. 4 (Xu et al., 2023). Polymer solution is forced through drum spinnerets revolving at a very high speed, creating a centrifugal force that extends the polymer solution jet produced under high pressure, forming nanofibers. Electrospinning is superior for producing ultra-fine and highly aligned nanofibers, whereas centrifugal spinning is significantly faster and more suitable for high-volume industrial production. Figure 4 also illustrates the basic mechanism of electro-centrifugal spinning, which is basically a combination of electrospinning and centrifugal spinning, utilizing the key advantages of both, producing finer nanofibers like those produced by electrospinning but at a faster speed than the electrospinning process. It is difficult to scale up the electrospinning process for industrial applications because of safety issues associated with high-voltage electricity use, but many centrifugal spinning machines are commercially used for the manufacturing of nanofibrous membranes for various applications.

It is difficult to produce nanofibers from 100% pure chitin and its derivatives because the polymer chains in their solutions exhibit limited chain entanglement and low relaxation times, hindering their electrospinnability, causing the breaking of polymer jets into droplets instead of converting them into fibers. As a result, they are frequently blended with other high-molecular-weight fiber-forming polymers, including poly(ethylene oxide) (PEO) (Tezcan et al., 2025), polyvinyl alcohol (PVA) (Lee et al., 2024), or polycaprolactone (PCL) (Erickson et al., 2015). In the textile industry, CS nanofibers are used as a sustainable and functional coating for textiles, endowing fabrics with properties such as high antibacterial activity, UV protection, and enhanced hydrophobicity (Taheri and Khajeh-Amiri, 2020).

4. Methods to Increase Strength of Fibers

To improve dry strength as well as wet strength of fibers, various physical and chemical strategies have been studied, and the key strategies are illustrated in Fig. 5. Physical methods may include drawing, blending with other polymers and additives, and process optimizations. The chemical methods may include chemical modifications, crosslinking, and polymeric grafting.

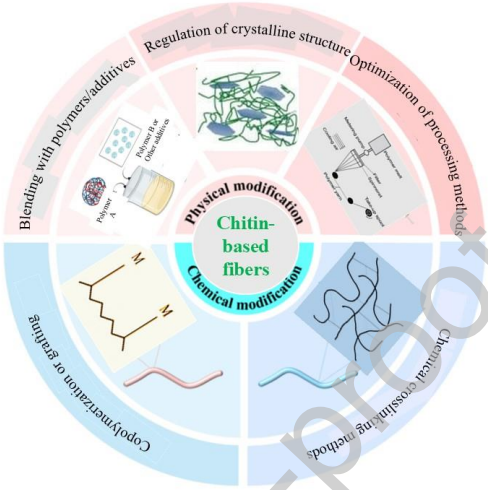


Fig. 5 Methods to enhance the tensile strength of chitin fibers

4.1. Crosslinking

The initial studies used various crosslinking agents including epichlorohydrin (ECH) (Wei et al., 1992), glyoxal (Yang et al, 2005), glutaraldehyde (Knaul et al., 1999a), but the recent studies used aziridine (Li and Tang, 2016a), tripolyphosphate/ursolic acid (Hérnandez Vázquez et al., 2024), diepoxy (Li et al., 2022; Li and Tang, 2016b), genipin and hexamethylene-1,6-diaminocarboxysulphonate (Austero et al., 2012), and *N*-ethyl-*N*′-(3-dimethylaminopropyl)carbodiimide (EDC)- activated heparin (Albanna et al., 2013). Wei et al. (1992) produced fibers from a 4% crab shell CS solution dissolved in 2% AA that were extruded into a coagulation bath containing 0.05 mol/L ECH in a 10% NaOH solution, followed by crosslinking with phosphate ions (Wei et al., 1992) and various dialdehydes (Knaul et al., 1999a; Lee et al., 2004b). In the case of dialdehydes, the tensile strength of the fiber considerably improved (Knaul et al., 1999b), and the crosslinking at higher temperatures (e.g., 70 □) provided a better increase in tensile strength than at lower temperatures (Yang et al., 2005). However, the increase in strength achieved is inadequate, and crosslinking can also negatively affect the fiber's biodegradability, elongation, and enhancement of orientation, crystallinity, and strength by physicomechanical processing, such as drawing (Li and Tang, 2016a).

4.2. Blending with other polymers and additives

The incorporation of compatible low-molecular-weight CS (Bentley et al., 2022) and PVA (Cerqueira et al., 2024) into a CS spinning dope can improve the strength of the produced fibers. It was reported that the wet spinning of a CS/PVA (55%/45%) fiber in a potassium hydroxide (KOH)/ethanol coagulation bath followed by crosslinking with tripolyphosphate exhibited tensile strength comparable to that of commercial sutures (Huang et al., 2021). Fiber is also produced from the blends of chitosan butyrate (CSB) and CA by wet spinning, which showed better hydrophobicity than the CS fiber (El-Tahlawy et al., 2007). Although blending CS with other polymers enhances various properties of the resultant fibers, spinning CS fiber by mixing with other natural polymers using conventional wet spinning machinery can be challenging (Watthanaphanit et al., 2009; Sibaja et al., 2015). The addition of caseinate to CS solution only slightly improved the tenacity of the fibers relative to those made from 100% CS (Peniche et al., 2024). Not only polymer blending, but also the modification of CS with CCA and grafting with mPEG was explored (Bao et al., 2020; Zhou et al., 2023). The CCA-m-CS fiber exhibited enhanced tensile strength along with fluorescence, and the CS-g-mPEG showed solid-state phase-change behavior.

Not only polymers but also the addition of various nanostructured materials, such as CS whiskers (Kalliola et al., 2018), CelNF (Tran et al., 2025), and PVA (Cerqueira et al., 2024) into a CS spinning dope can improve the crystallinity and enhance the strength of the resultant fibers, as they can act as nucleating points. The addition of graphene oxide (Li et al., 2014), ChNF of 600–800 nm in length and 11–12 nm in diameter (Yudin et al., 2014), and nanocellulose (Nechyporchuk et al., 2020) to CS produced fibers with excellent mechanical properties. The wet-spun CS fiber coated with manganese iron layered double hydroxide (LDH) exhibited high tensile strength (Khalili et al., 2021). Textiles made from wet-spun CS fibers containing silica microparticles exhibited high reflectivity (82.3%), high infrared emissivity (95.6%), and passive radiation cooling (Chen et al., 2023).

5. Structure-Property Relationship

5.1. Molecular orientation and crystallinity

The structure-property relationship of fibers made from chitin and its derivatives depends heavily on their MW, crystalline orientation, degree of deacetylation (in the case of chitin derivatives), and also fiber spinning methods, solvents, coagulation bath compositions, and fiber draw ratio. These structural parameters directly dictate mechanical and functional properties, degradation rates, and biological interactions (Marin et al., 2025; Staszczyk et al., 2026). While early literature on chitin spinning dates back nearly a century, comprehensive studies detailing the precise structure-property relationships of regenerated chitin and derivative fibers, such as orientation and crystallinity, other than their mechanical properties, remain relatively scarce. Fibers regenerated from an 8% solution of 100% CS dissolved in 2% AA solution by dry-jet wet spinning exhibited a degree of preferred relative orientation of 86% (Ota et al.,

2021). However, for the fibers regenerated from an 8% solution of 50/50 CS/Cel blend, the degree of preferred relative orientation was reduced to 77%, and the degree of crystallinity also decreased, suggesting the addition of Cel to chitosan affected its molecular orientation. On the other hand, fibers made from partially deacetylated ChNF extruded into acetone exhibited an orientation index, crystallinity, and strength of 0.72, 70%, and 245.8 ± 39.9 MPa, respectively (Wang et al., 2020). However, the same fibers prepared by extruding into NaOH solution exhibited a higher orientation index (0.77) and lower crystallinity (59%) and strength (151 ± 18.7 MPa), possibly due to dissolution of chitin in aqueous NaOH solution via a deacetylation reaction, which decreased their crystallinity.

5.2. Mechanical properties

Table 1 presents the mechanical properties of fibers produced from chitin and its derivatives by utilizing various spinning methods, solvents, coagulation baths, and spinning dope additives. Various natural fibers, such as silk fibers from Bombyx mori, wool, jute, cotton, and hemp fibers, have tensile strengths of 500, 120–174, 200–800, 264–800, and 310–900 MPa, respectively (Shao and Vollrath, 2002; Cheung et al, 2009; Toskas et al., 2013). On the other hand, the tensile strength of standard rayon and lyocell fibers typically ranges from 77.3– 340 and 64.4–556 MPa, respectively (Adusumali et al., 2006; Fazeli et al., 2024). The dry tensile strength of earlier CS fibers produced from their AA solution by wet spinning ranges from 38.4 to below 100 MPa; even after crosslinking, the strength was poor (Lee et al., 2007). However, with the advancement in processing and solvents, some of the recently developed CS fibers have tensile strength comparable to the strongest natural fibers (Chen et al., 2021; Li et al., 2012b).

The wet-spun chitin and chitosan fibers have lower wet strength compared to their dry strength, like regenerated Cel fibers (Gan et al., 2017; Moriam et al., 2021). Compared to other natural fibers, wet-spun CS fiber has a poor tensile strength. Although CS and quaternized chitosan (qCS) fibers can be made from fungal chitin (Wijayarathna et al., 2024), fibers made from fungal chitin are weaker than fibers made from shrimp chitin. CS and qCS fibers can be dyed with anionic dyes, and CMCS fibers can be dyed with cationic dyes with high absorption, without using any salt, reducing pollutant load in the generated effluent (Ge and Luo, 2005). The highest strength was exhibited by fibers produced from CS dissolved in KOH/urea using an aqueous potassium chloride (KCl) coagulation bath, and [Gly].HCl using an aqueous Na_2SO_4/ethanol coagulation bath by wet spinning, and chitin dissolved in phosphoric acid (PA) using an aqueous ethanol coagulation bath by dry-jet wet spinning, and the tensile strength exhibited by them is 878 ± 123 (Chen et al., 2021), 527.8 (Li et al., 2012b) and 330 ± 6.5 (Feng et al., 2025) MPa respectively. The gel-spun chitin fiber made from squid pen also exhibited very high strength, 295 MPa (Notin et al., 2006). Of the pure CS fibers, those produced from CS of 83% DD by wet spinning using a 50/50 mixture of 10% aqueous solution of NaOH and ethanol exhibited a maximum tensile strength of 220 MPa (Yudin et al., 2014), considerably lower than the chitin fiber, but still higher than the average strength of wool fibers.

The mechanical properties of fibers can be influenced by several factors, including the MW, solvents used, the composition of coagulation baths, spinning methods, additives used, and the drawing ratios used during fiber manufacturing.

Table 1 Mechanical properties of neat chitin and chitin derivatives and their composite fibers produced by various methods

	Composition of fibers	Spinning method	Source	DD (%)	Solvent	CS conc. (%)	Coagulation bath composition	Tensile strength (MPa)	Elongation (%)	Reference
	CS	Wet	n/a	84	2% AA	5	Aq. 5% NaOH	171.5 (47.0)	5.6	East and Qin, 1993
	CS	Wet	n/a		2% AA	n/a	Aq. 10% NaOH + 30% Na_2SO_4	113.7	8.2–10.4	Hirano, 2001
	CS	Wet	Red crab		2% AA	4	Aq. 10% NaOH	153.2	9.0	Lee, 2003
	Chitin	Dry	Fungal	47.0	2% AA 2% LA	4-5	n/a	62.8 ± 3.2 mono 103.0 ± 30.2 multi	14.3 ± 1.8 2.35 ± 0.9	Lindh et al., 2024
	Chitin	Wet	Shrimp Fungal	23.7 15.8	AdA	3	50/50 aq. 10% NaOH/ethanol	308.0 ± 18.4 226.8 ± 72.5	22.7 ± 4.0 16.5 ± 3.5	Perrin et al., 2022
	CS	Wet	Fungal	n/a	2% LA	n/a	Ethanol	55.0	7.0	Svensson et al., 2021
	CS	Wet	Fungal	n/a	2% AA	n/a	Ethanol	72.3	4.0	
	CS	Wet	Fungal	n/a	2% LA	2	Ethanol	65.0 ± 4.2 mono, unwashed	4.0 ± 0.1	Wijayarathna et al., 2024
	CS	Wet	Fungal	n/a	2% LA	2	Ethanol	140.5 ± 2.9 mono, washed	2.9 ± 0.9	
	Chitin	Dr-jet wet	n/a	n/a	PA	10	50% Aq. ethanol	330 ± 6.5	n/a	Feng et al., 2025
	β-ChNF	Wet	Squid pen	n/a	2% AA	0.6	Aq. 10% NaOH	251.3 ± 12.5 4.5	n/a	Chen et al., 2022a
Fibers from chitin or CS alone	CS	Wet	Crab shell	85.0	2% AA	4	Aq. 10% NaOH + ethanol	150.0	5.2	Mohammadkhani et al., 2021
	CS	Wet	n/a	65	7.2% (*w*) LiOH/6.0% urea	3	6%–8% H_2SO_4 + ethanol	162.6 ± 4.3	11.2 ± 0.6	Li et al., 2012a
	CS	Wet	n/a	86	[Gly]HCl	n/a	Aq. Na_2SO_4/C_2H_5OH	527.8	n/a	Li et al., 2012b
	CS	Wet (gel)	Shrimp	68	KOH/urea	7	Aq. KCl	878 ± 123	n/a	Chen et al., 2021
	CS	Wet Dry-jet wet	Snow crab shell	90	[Gly]HCl/[Bmim]Cl	5	Aq. 10% NaOH and then ethanol	217.5 (159.5) 306.6 (131.4)	8.1 11.9	Ma et al., 2013
	CS	Wet	n/a	90.0	[Bmim]Ac	6	Deionized water	59.7	33.5	Kuznik et al., 2022
	CS	Wet	Crab shell	84.3	2% AA	4	10% NaOH solution	138.5 (123.8)	16.2 10.1	Lee et al., 2004b
	CS	Wet	Squid pen	98	2% AA	5	Aq. 10 mol/L NaOH + 0.4% caseinate	192.2	5.0 ± 0.2	Peniche et al., 2024
	CS	Wet	n/a	95	2% AA	4	NaOH + ethanol	96.1	10.5	Zhou et al., 2023
	CS	Wet	n/a	83	2% AA	4	Aq. 10% NaOH + ethanol	220.0	n/a	Yudin et al., 2014
	CS	Wet	Squid pen	97.5	2% AA	4	Aq. 3mol/L NaOH	120.0	8.0	Khalili et al., 2021
	Chitin	Gel	Squid pen	2.7	2% AA	0.5	Aq. 20% ammonia	295.0	5.3	Notin et al., 2006
	Chitin	Dr-jet wet	n/a	n/a	PA	10	50% Aq. ethanol	330 ± 6.5	n/a	Feng et al., 2025

	ChNF	Wet	Crab shell	19.5	Water	1.5	Acetone	245.8 ± 39.9	7.1 ± 3.8	Wang et al., 2020
	CS	Wet	Crab shell	84.2	2% AA	4	Aq. 10% NaOH	156.9	9.1	Marquez-Bravo et al., 2021
	CS	Wet	Shrimp shell	67.4 70.6	2% AA	5	14% NaOH + 2% NaOH	38.4 80.4	16.2 6.9	Judawisastra et al., 2015
Cross-linked fibers and fibers from CS derivatives	CS cross-linked with 4.76 g/L ECH	Wet	Crab shell	84.3	2% AA	4	Aq. 10% NaOH	128.1 (131.6)	11.5 (10.2)	Lee et al., 2004b
	CS x-linked with 4.76 g/L ECH	Wet	Red crab shell	n/a	2% AA	4	Aq. 10% NaOH + 10% SA	123.8 (115.2)	13.6 (14.7)	Lee et al., 2007
	CS x-linked with PHP	Wet	Shrimp shell	95 ± 3	4% AA + 4% methanol	4	Aq. 1 mol/L KOH	173.8	28.4	Knaul et al., 1999a
	CS x-linked with 4% glyoxal	Wet	n/a	91	2% AA	3.5	Aq. NaOH + Na_2SO_4	215.7	n/a	Yang et al., 2005
	CCA-m-CS	Wet	n/a	95	2% AA	4	NaOH + ethanol	103.9	6.0	Zhou et al., 2023
	CS-g-mPEG	Wet	n/a	85	2% AA	4	Aq. 5% NaOH + ethanol	133.4	6.1	Bao et al., 2020
CS composites	10% LMW and 90% HMW CS	Wet	Squid pen	97.5	2% AA	4	Aq. 1 mol/L NaOH	254.9	5.9	Bentley et al., 2022
	CSB/CA 45/55	Wet	Crab shell	85	NMP	n/a	Aq. H_2SO_4	43.1	6.9	Lee, 2003
	CSB/CA 45/55，SM-treated						Aq. H_2SO_4	67.7	11.3	
	95%/5% CS/ChNC	Wet	n/a	n/a	3% AA	3	20 g/L NaOH + 100 g/L Na_2SO_4	198.0	3.2	Yan et al., 2014
	25%/75% CS/Cel	Wet	n/a	88	$[C_2C_1Im][OPr]$	n/a	Aqueous sucrose	294.0	5.0	Mundsinger et al., 2015
	50%/50% CS/Cel	Wet	n/a	88	$[C_2C_1Im][OPr]$	n/a	Water	218.0	8.0	Ota et al., 2021
	25%/75% CS/Cel							179.0	11.0	
	50%/50% CS/Cel	Dry-jet wet						197.0	5.0	
	25%/75% CS/Cel							194.0	10.0	
	99.7% CS/ 0.3% CS-NF	Wet	Crab shell	83	2% AA	4	Aq. 10% NaOH + ethanol	290.0	n/a	Yudin et al., 2014
	99.6% CS/0.4% LDH	Wet	n/a	80–95	10% AA	4.2	Aq. 4 mol/L NaOH	170.0	5.2	Khalili et al., 2021
	90.0% chitin + 10% CelNF	Gel	Squid pen	2.5	2% AA	4	Aq. 3 mol/L NaOH	163.0	n/a	Marquez-Bravo et al., 2021

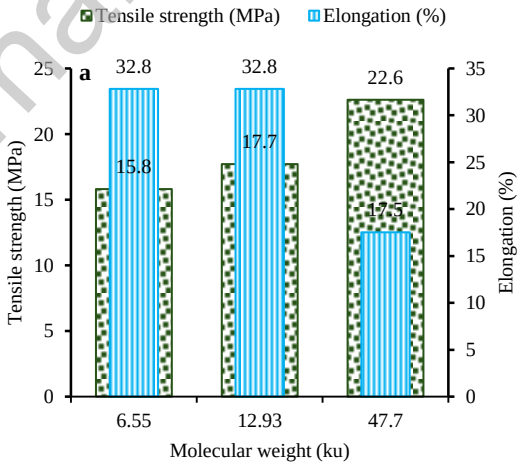
Notes: In the 9th column, inside brackets, wet strengths were provided wherever data were available. Abbreviations: CS = chitosan, ChNF = chitin nanofibrils, AA = acetic acid, AdA = adipic acid, LA = lactic acid, sodium hydroxide = NaOH, potassium hydroxide (KOH), lithium hydroxide (LiOH), ECH = epichlorohydrin, ChNC = chitin nanocrystals, Cel = cellulose, CA = cellulose acetate, CSB = chitosan butyrate, PA = phosphoric acid, NMP = N-

methylpyrrolidone, CS-NF = chitosan nanofibrils, LDH = layered double hydroxide, CelNF,= cellulose nanofiber, [Gly]HCl = glycine hydrochloride, [Bmim]Cl = 1-butyl-3-methylimidazolium chloride, [Bmim]Ac = 1-butyl-3-methylimidazolium acetate, $[C_2C_1Im][OPr]$ = 1-ethyl-3-methylimidazolium propionate, H_2SO_4 = sulfuric acid, and Na_2SO_4 = sodium sulfate.

5.2.1. Effect of DD and MW

The DD and MW of chitin and CS can influence the mechanical properties of fibers, but this relationship is not always linear (Carrera et al., 2023; Lindh et al., 2024). X-ray diffraction (XRD) analysis of chitin and regenerated chitin fiber shows that the distribution of N-acetyl groups is more random in chitin than in fibers produced from it (Hirano et al., 1993). The CS with a higher DD has more crystalline regions than the CS with a lower DD (Yan et al., 2014; Zhong et al., 2019). Higher DD and MW generally lead to increased tensile strength and elastic modulus of the fibers. Higher MW polymer chains offer more entanglement and stronger interactions, contributing to greater fiber strength.

Figure 6a shows the effect of the molecular weight of CS on the tensile strength and elongation of CS films (Zhong et al., 2019). The tensile strength of CS films increases with an increase in the MW of CS, but the elongation decreases with an increase in MW. An increase in crystallinity of a polymer generally reduces the elongation (flexibility/stretchability) and increases the stiffness of a fiber made from it. Figure 6b shows the effect of DD of CS on the tensile strength and elongation of the CS fiber without methanol treatment (Judawisastra et al., 2015). The CS fiber produced from higher DD showed higher tensile strength, but lower elongation, compared to the fiber produced from lower DD. In the case of methanol treatment, the fiber produced from higher DD showed higher tensile strength and elongation compared to the fiber produced from lower DD, as shown in Fig. 6c.



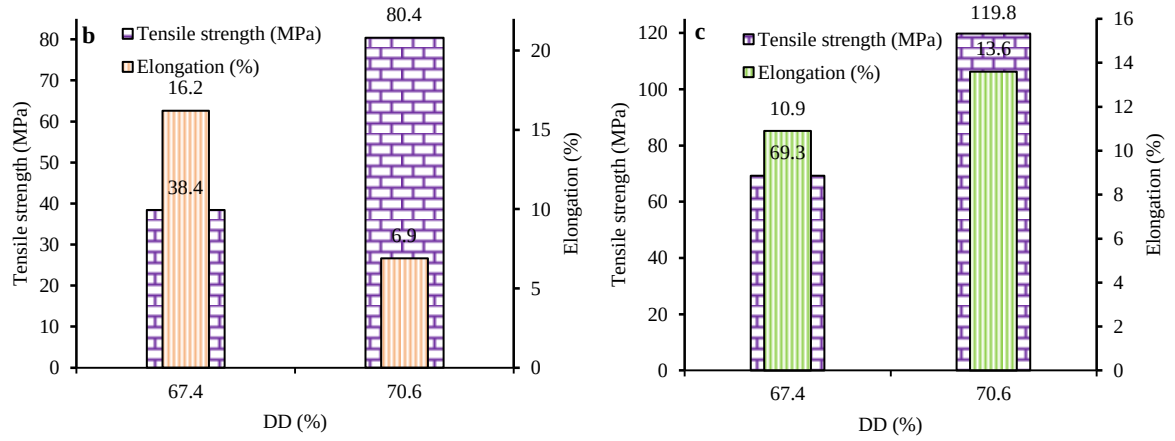


Fig. 6 Effect of MW on CS films (a) and degree of deacetylation (DD) on the tensile strength and elongation of CS fibers treated without (b) and with (c) methanol. These charts were prepared using data from references (Judawisastra et al., 2015; Zhong et al., 2019).

5.2.2. Effect of coagulation bath compositions and temperature

The coagulation bath temperature and composition can affect the mechanical properties of the CS. Different solvents, concentrations, and temperatures in the bath affect the fiber's structure and, subsequently, its mechanical properties. Factors like the type of acid/alkali used and the presence of a chitin/CS non-solvent like ethanol/methanol can determine the final structure, porosity, and mechanical properties of the resulting fiber. Only a few studies reported the effect of coagulation bath compositions on the tensile strength of CS fibers. Although various types of coagulation baths were studied for the regeneration of CS fibers, the CS solvent concentrations, DD, bath compositions, coagulation bath solvents, temperature, and drawing speeds used by various studies were different, making a comparison of various coagulation bath compositions difficult. Table 1 shows the effect of coagulation bath compositions and temperature on the mechanical properties of fibers made from chitin and its derivatives. Chitin fibers regenerated from chitin dissolved in N,N-dimethyl acetamine/5% lithium chloride and extruded into a water coagulation bath show that the bath temperature highly affected the tensile strength of the produced fibers (Lindh et al., 2024). The tensile strength of the fiber increased from 80 to 182 MPa when the coagulation bath temperature increased from 5 to 60 □. da Silva et al. (2025) reported that the crystallinity of CS fiber was higher for CS dissolved in aqueous solutions of AA and extruded into an ethanol coagulation bath, while lactic acid induced greater structural disorder. The CS fibers wet-spun in an ethanol coagulation bath had more homogeneous surfaces compared to a methanol coagulation bath, which produced rougher filaments.

5.2.3. Effect of solvents, spinning methods and drawing

The solvent used for the dissolution of chitin and its derivatives also affects fiber strength by interacting with their extensive network of hydrogen bonds. Chitin is notoriously insoluble in common solvents due to tight polymer packing, while chitosan is easier to dissolve in acidic water because its amino groups become charged and interact with water molecules (Qian et al., 2023). Specialized solvents, such as ionic liquids, can break these internal bonds to dissolve, swell, or modify them. Table 1 shows the effect of chitin solvents, spinning methods, and drawing on the mechanical properties of fibers made from chitin and its derivatives. The CS dissolved in 7.2% (*w*) LiOH and 6.0% (*w*) urea was spun into a coagulation bath of 8% H_2SO_4, and ethanol produced a fiber of 162.57 ± 4.3 MPa tensile strength (Li et al., 2014). The CS fiber spun from its glycine hydrochloride ([Gly]HCl) IL solution into a Na_2SO_4/ethanol aqueous solution produced a fiber with a tenacity of 37.7 cN/tex (369.7 MPa) compared to 8.6 cN/tex (84.3 MPa) tenacity exhibited by the fiber produced from the same CS using aqueous AA solution (Li et al., 2012a).

Dry-jet wet-spun fibers generally show higher strengths than wet-spun fibers made from the same polymer because the air gap allows for a higher stretch ratio (draw ratio) and better molecular orientation before the polymer completely solidifies. For example, dry-jet spun CS fiber made from its [Gly]HCl and Bmim]Cl solution and extruded into successive 10% NaOH and ethanol coagulation baths exhibited a tensile strength of 306 MPa, but when fibers were made from the same spinning dope by wet spinning using the same coagulation bath only exhibited a tensile strength of 217.5 MPa (Ma et al., 2013). Ota et al. (2021) observed that for 50/50 blending of CS and Cel, wet-spun fibers showed higher strength (218 MPa) compared to the dry-jet wet-spun fibers (197 MPa), but for the 25/75 blends, dry-jet wet-spun fibers showed higher strength (194 MPa) than the wet-spun fibers (179 MPa). Not only the spinning methods, but the drawing and drying conditions have a role in determining fiber properties. The fiber dried by air drying shows a much higher extensibility than that dried by radiant heating (Qin, 1990; Toskas et al., 2013), due to differences in thermal stress, moisture-induced plasticity, and molecular chain relaxation and densification (Wang et al., 2025). Fibers made from CS of 67.4 and 70.6% DD by wet spinning and extruding into a coagulation bath of 14% aqueous solution of NaOH exhibited a tensile strength of 38.4 and 80.4 MPa for air drying but increased to 69.3 and 119.8 MPa, respectively, after the drying treatment with 30% aqueous methanol (Judawisastra et al., 2015).

The drawing treatment of fibers after the spinning process has a great effect on fiber strength. Drawing stretches extruded polymer filaments to align their molecular chains along the fiber axis, transforming weak, highly extensible structures into strong, high-performance fibers by affecting their crystallinity, orientation, and ultimately the strength of fibers (Zhang et al., 2026). The tenacity increased from 41.2 to 69.6 MPa (4.2–7.1 cN/tex) after drawing at a draw ratio of 1.0 when the CS concentration in the spinning dope increased from 6% to 8% (Nechyporchuk et al., 2020). In the case of 6% CS solution, the tenacity increased from 41.2 to 76.0 MPa (4.2–7.75 cN/tex) when the draw ratio was increased from 1.0 to 1.33.

The increase in the draw ratio increased the tenacity of CS fiber made from 8% CS solution from 69.6 to 95.1 MPa (7.1–9.7 cN/tex) when the draw ratio was increased from 1.0 to 1.77. Similarly, the tensile strength of wet-spun CS before drawing was 150 MPa, which increased to 220 MPa after drawing at a draw ratio of 1.2 (Yudin et al., 2014).

5.2.4. Effects of crosslinking and grafting

Crosslinking of CS fibers greatly influences their mechanical properties. It was found that crosslinking slightly reduced the dry strength of CS fiber but greatly increased its wet strength by decreasing its water absorbency and swelling due to the blocking of hydrophilic groups of CS. Table 1 shows the effect of crosslinking and grafting on the mechanical properties of fibers made from chitin and its derivatives. Non-crosslinked CS fiber produced by wet spinning exhibited a dry tensile strength of 138.5 MPa, which was reduced to 128.1 MPa when the ECH concentration was increased to 4.76 g/L (Lee et al., 2004b). Conversely, ChNP fiber before and after crosslinking with phytic acid (ChNP-c-PhA) exhibited 330 and 360 MPa tensile strength (Feng et al., 2025). Similarly, the non-crosslinked CS fiber had a wet tensile strength of 123.8 MPa, which increased to 131.6 MPa when the ECH concentration increased to 4.76 g/L. The swelling ratio of the fiber decreased from 52% to 10.2% when the ECH concentration increased from 0.95 to 23.8 g/L, and the wet tensile strength also increased from 122.9 to 136.8 MPa. Even the CS fiber crosslinked with the lowest concentration of ECH (0.95 g/L) was insoluble in a 2% AA solution. The addition of sodium acetate (SA) to the NaOH coagulation bath showed a positive effect on increasing the dry and wet tensile strength of ECH-crosslinked CS fiber. The addition of 10% (*w*/*w*) SA increased the dry strength of the ECH-crosslinked fiber from 112.6 to 123.8 MPA and wet strength from 104.8 to 115.2 MPa (Lee et al., 2007). The CS fiber produced from 4% CS (95% DD) dissolved in 4% AA + 30% by volume of methanol, crosslinked with potassium hydrogen phthalate (PHP), exhibited a dry tensile strength of 173.8 MPa, considerably higher than the ECH-crosslinked CS fiber (Knaul et al., 1999a). On the other hand, the wet-spun CS fiber crosslinked with glyoxal exhibited excellent tensile strength (215.7 MPa) when the crosslinking reaction was carried out at 40 □ for 70 min (Yang et al., 2005). Of the CS derivatives studied, fibers produced from CCA-m-CS and CS-g-mPEG showed quite poor tensile strength (Bao et al., 2020; Zhou et al., 2023).

5.2.5. Effects of mixing of other polymers and/or additives

Table 1 shows the effect of mixing of other polymers and/or additives on the mechanical properties of fibers made from chitin and its derivatives. Blending involves using a compatibilized high-strength or rigid polymer with a softer matrix using additives called compatibilizers to lock the phases together and transfer external loads efficiently across microscopic boundaries so the material resists cracking and deformation. However, the wrong selection of polymer may affect the strength of the resultant fiber. For example, the addition of sodium caseinate to CS in the spinning dope was found to decrease the strength of the fiber

from 208.9 MPa for the 100% CS to 176.5 and 147.1 MPa, respectively, for 0.1% and 1.0% sodium caseinate (Sibaja et al., 2015). However, the addition of Cel to chitosan at a 75/25 ratio considerably increased the tensile strength of the fiber (294 MPa) produced by wet spinning compared to the 100% CS fiber (Mundsinger et al., 2015). The addition of 0.3% ChNF to CS also produced fiber with a tensile strength of 290 MPa (Yudin et al., 2014). Similarly, fibers produced from a mixture of CS of 10% low MW and 90% high MW CS also produced a very strong fiber (254.9 MPa) compared to fibers made from 100% high MW CS (Bentley et al., 2022). Fiber produced from CS containing 5% ChNC by wet spinning showed good strength, 198 MPa (Yan et al., 2014). It was also reported that CS/collagen fibers produced from a 20/80 mixture of CS/collagen, when the collagen concentration was 80%, the tensile strength of the resultant fiber reached 178.8 MPa, which further increased to 198.2 MPa when crosslinked with glutaraldehyde (Ding et al., 2023).

The incorporation of nucleating agents such as nanoparticles and nanowhiskers to CS can also enhance the strength of its fibers. A range of nanoparticles and nanowhiskers, such as reduced graphene oxide (rGO), chitin nanocrystal (ChNC), chitin nanofibrils (ChNF), and CelNFs, were studied to enhance CS fiber strength (Zhang et al., 2018; Nguyen, 2021). The rGO-incorporated dry-jet wet spun CS crosslinked with genipin showed intrinsic fluorescence along with high tensile strength. The CS fibers loaded with 5% ChNC showed excellent tensile strength of 215.7 MPa (Nguyen, 2021). The above-mentioned results suggest that the addition of ChNF, CelNF, and LMW CS had a beneficial effect in enhancing the tensile strength of the resultant fibers.

5.3. Morphologies and microstructures

5.3.1. Surface morphologies

Figure 7 (top) exhibits the morphology and fiber diameter distribution of nanofibers produced from CS containing various weight (%) of polyethylene oxide (PEO) by electrospinning (top) and centrifugal spinning (bottom) (Furer et al., 2022; Tien et al., 2022). The nanofibers produced from CS containing 5% PEO by electrospinning produced very smooth fibers with uniform diameter, without forming visible beads. The average diameter of the produced fibers was only 300 nm, which decreased after 4 h of crosslinking with glutaraldehyde vapor. On the other hand, the nanofibers produced from CS with various weight (%) of PEO by centrifugal spinning are coarser compared to the nanofibers produced by electrospinning. The average diameter of nanofibers produced from a 50/50 mixture of CS and PEO by centrifugal spinning was 850 ± 250 nm, which decreased with an increase in PEO weight (%). The finest fibers were produced by CS containing 98% PEO, but when the PEO content was decreased to 95%, the mixture produced nanofibers with beads.

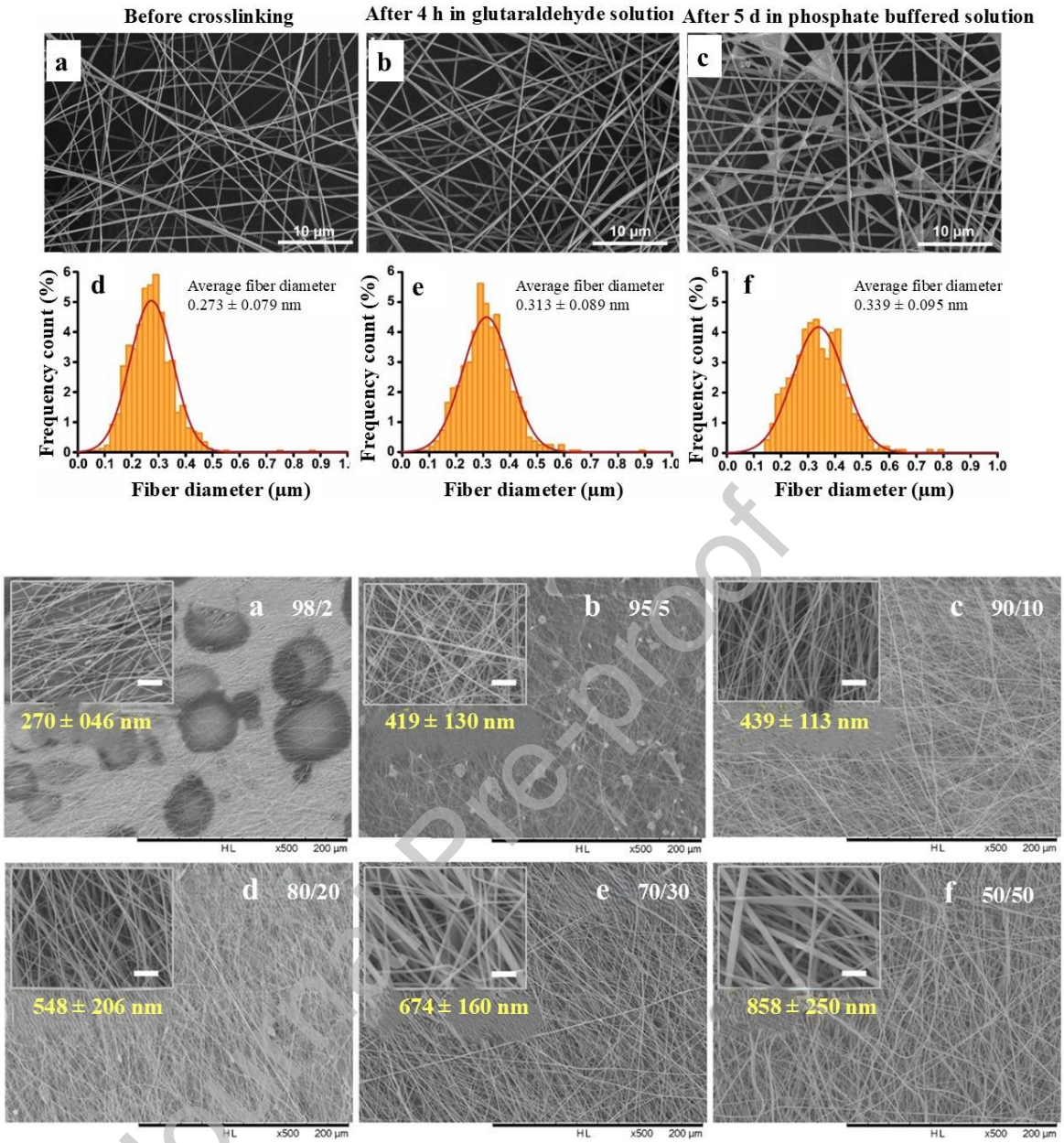


Fig. 7 Morphology and fiber diameter distribution of nanofibers produced from CS containing various polyethylene oxide (PEO) weight (%) by electrospinning (top) and centrifugal spinning (bottom) (Furer et al., 2022; Tien et al., 2022). Reproduced with permission from Elsevier.

Figure 8 shows the optical micrographs of the cross-section and scanning electron microscopic (SEM) images of the surface of fibers made from CS with various DDs (Li et al., 2022). The surface of fibers produced from chitin with 82.8% (l), 84.8% (f), 82.2% (i), and 88.1% (j) DD was very smooth, but the fibers produced from chitin with 87.8% (d), 95.9% (e), 84.3 (k), and 83.2% (m) DD had grooves on their surface. The cross-section of chitin fibers produced from CS solutions of 82.2% (i) and 88.1% (j) produced fibers with a round shape, but 84.3% (k), 82.8% (l), 83.2% (m), and 87.8% (d) produced polygonal-shaped

fibers. On the other hand, the cross-section of fibers produced from chitin of 95.9% (e) and 84.8% DD was irregular. The effect of DD on the surface and cross-section of the fiber was inconsistent and did not show a trend.

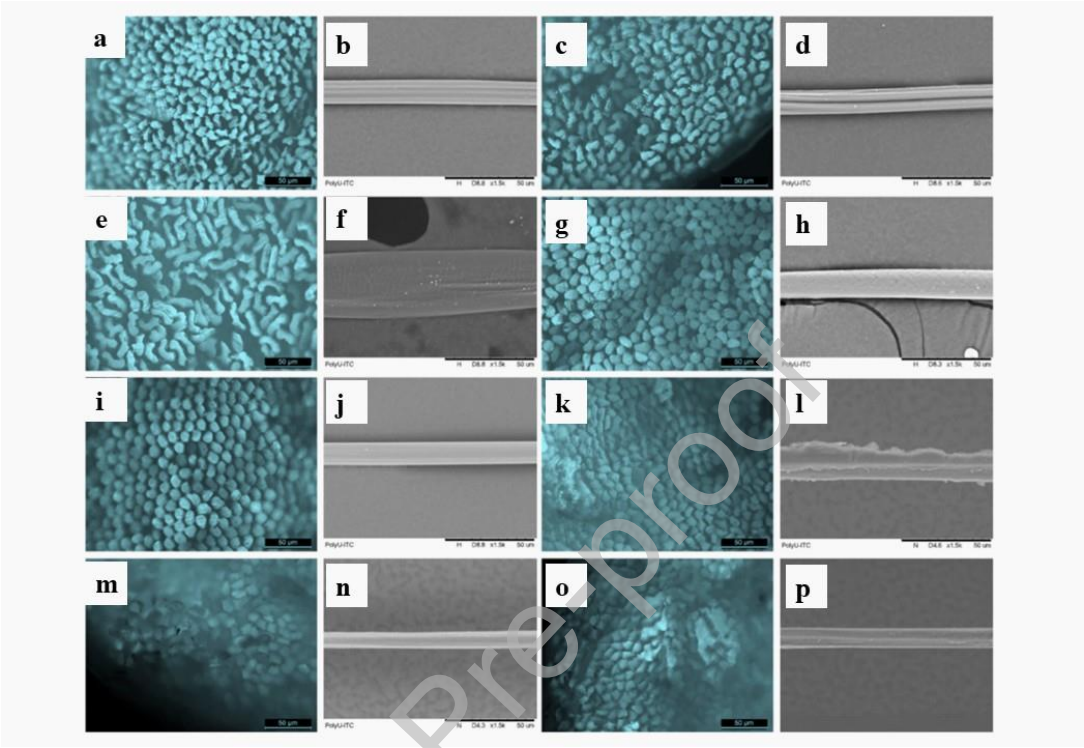


Fig. 8 Optical images of cross-section and scanning electron microscopic (SEM) images of the surface of fibers made from CS with various DDs (Li et al., 2022). Reproduced with permission from Elsevier.

5.3.2. Microstructures

The microstructure, crystallinity, and orientation of CS fibers could be affected by spinning conditions (speed, temperature, drawing ratio, etc.). The CS fibers produced by wet, dry-jet wet, and gel spinning typically exhibit rough, grooved, or wrinkled surface morphology, which can be influenced by the MW of the CS and the conditions of the coagulation bath. The surface often displays micro-range features, and at higher magnifications, nanograins or other structural features may be visible, depending on the additives or processing conditions. In some cases, particularly when additives like caseinate are incorporated, nanograins or other surface features can be observed at higher magnifications. While some fibers may have a smoother surface, this is less common and may be influenced by the specific processing parameters. For example, Figs. 9a–9d show SEM images of surface morphologies of CS and also CS-g-mPEG fibers with 1∶1, 1∶2, and 1∶3 CS to mPEG ratios made from CS and CS-g-mPEG dissolved in 2% AA solution but wet-spun into coagulation baths containing 5% NaOH aqueous solution, and 5% NaOH solution containing

ethanol, respectively (Bao et al., 2020). The surface of the CS fiber had many rough grooves and irregular ridges, which were improved for the CS-g-mPEG fibers, especially after increasing the CS to mPEG ratios. The grafting of mPEG onto CS macromolecular chains increased their entanglement and intermolecular hydrogen bonding, resulting in a tighter molecular chain stack, creating fibers with a smoother surface. Figures 9e, 9f, and 9g show cross-sectional images of CS made by wet spinning, and the surface and cross-sectional images of CS fibers made by dry-jet wet spinning, respectively (Ma et al., 2013). The CS fibers in both cases were made by dissolving chitosan powder in [Gly]HCl/[Bmim]Cl. The wet-spun fiber had many grooves in the longitudinal direction, but the dry-jet wet-spun fiber showed a smooth surface. The cross-sectional images show that the shape of the wet-spun fiber was quite round, but the dry-jet wet-spun fiber was quite irregular. Figure 9h shows the powdered X-ray diffraction (XRD) and the two-dimensional (2D) wide-angle X-ray diffraction (WAXD) patterns of CS and CS-g-mPEG fibers (Bao et al., 2020). Both fibers exhibit two peaks of (110) and (130) lattice diffraction at $2\theta = 20.4°$ and 29.5°, but the intensity was considerably higher for the CS-g-mPEG1:1 fiber than the CS fiber, indicating that the CS-g-mPEG1:1 fiber had a higher crystallinity compared to the CS fiber. In the case of 2D WAXD, the CS-g-mPEG1:1 fiber exhibited more obvious and brighter equatorial arcs compared to the CS fiber, indicating the former fiber had better crystalline structures than the CS fiber. Figure 9i shows XRD and 2D WAXD patterns of fibers made from CS-g-mPEG1:1, CS-g-mPEG1:1, and CS-g-mPEG1:1 fibers. The peaks at $2\theta = 20.4°$ and 29.5° in the XRD patterns increased and the equatorial arcs in the 2D WAXD patterns were brighter in the order of CS-g-mPEG1:3 > CS-g-mPEG1:2 > CS-g-mPEG1:1, i.e. CS-g-mPEG1:3 fiber had a better crystalline structure than the CS, CS-g-mPEG1:1, and CS-g-mPEG1:2 fibers.

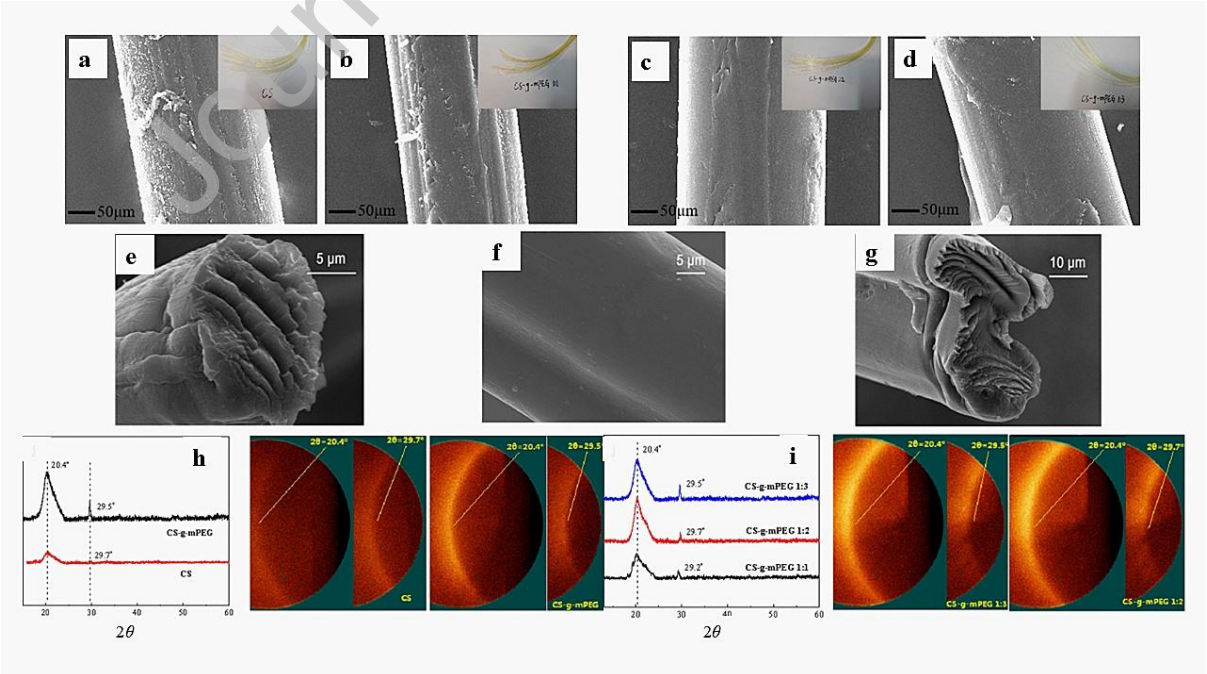


Fig. 9 The SEM micrographs surface of wet-spun CS (a), CS-g-mPEG 1,1 (b), CS-g-mPEG 1,2 (c), CS-g-mPEG 1,3 (d) (Bao et al., 2020), cross-section of CS (e), surface (f) and cross-section (g) dry-jet wet-spun CS (Ma et al., 2013), and X-ray diffraction (XRD) and two-dimensional wide angle X-ray diffraction (2D WAXD) of CS (h) and CS-g-mPEG (i) fibers (Bao et al., 2020).

5.4. Functional properties

5.4.1. Antibacterial properties

Chitin itself generally exhibits no inherent antibacterial activity due to its lack of water-solubility and absence of free amino groups. However, its various derivatives, such as CS and qCS, are well-known for their strong antimicrobial performance against a wide range of Gram-positive (e.g., *Staphylococcus aureus*) and Gram-negative (e.g., *Escherichia coli* and *Pseudomonas aeruginosa*) bacteria (Hassan, 2018). Quaternization of CS further increases its positive charge and also its solubility in water, increasing its antibacterial properties. By reducing microbial colonization on clothes, they help prevent cross-contamination, especially in hospitals, nursing homes, and public transport. Antimicrobial efficacy is often proportional to its cationic charge density (i.e., number of amino groups) and is affected by the MW (Murata et al., 2007; Másson, 2024). Generally, CS with a lower MW shows greater effectiveness against Gram-negative bacteria, while CS with a higher MW can be more effective against Gram-positive bacteria (Zheng and Zhu, 2003).

5.4.2. Antibacterial performance

Table 2 shows the antibacterial performance of pure CS fiber and fibers made from blends of CS and other polymers. The 100% wet-spun CS fibers made from various DD showed different effectiveness against *S. aureus*, *E. coli*, and *Candida albicans* (Li et al., 2022). Although fibers made from lower DD showed better antibacterial performance than the fibers made from higher DD, the results did not show any trends. The electrospun nanofibers made from PCL/CS (80%/20%) containing a small percentage of Chinese yam polysaccharide showed excellent antibacterial properties against *E. coli* and *S. aureus* (Zang et al., 2024). The fibers made from blends of PVA and CMCS (91/9) prepared by centrifugal spinning showed moderate antibacterial activity against *S. aureus* but very poor antibacterial activity against *E. coli* (Zhang et al., 2023). Electrospun nanofibers of qCS/poly(vinyl pyrrolidone) (PVP) and CS/PEO (80/20) showed excellent antibacterial activity against a wide range of bacteria (Ignatova et al., 2007). On the other hand, Fe_3O_4-modified CS and PVA showed quite poor antibacterial activity (Yang et al., 2023). The electrospun 80/20 blends of CS and PEO showed excellent antibacterial activity, but the CS/PVA fiber showed only moderate antibacterial activity (Arkoun et al., 2017).

Table 2 Antimicrobial performance of chitin fibers with various degrees of deacetylation (DD) against a broad spectrum of microbes

Fiber type	DD	Spinning process	Antibacterial performance (% killed) against				Reference
			S. aureus	*E. coli*	*C. albicans*	*S. Typhimurium*	
CS	82.2	Wet-spun	96.7	98.3	93.7	n/a	Li et al., 2022
	82.8		99.0	93.0	92.0		
	83.2		98.0	94.7	93.3		
	84.3		> 99.0	98.7	95.0		
	84.8		97.0	91.7	91.3		
	87.8		> 99.0	95.1	96.7		
	88.1		97.7	99.0	94.7		
	95.9		98.0	97.3	96.0		
PCL/CS 80%/20%	95.0	Electro	13.1 mm*	17.0 mm*	n/a	n/a	Zheng and Zhu, 2003
PVA/CMCS 90.9/9.1	85.0	Centrifugal	72.1	21.4	n/a		Zhang et al., 2023
qCS/PVP	n/a	Electro	100.0	98.8	n/a		Ignatova et al., 2007
Fe_3O_4-CS/PVA	80.0–95.0	Electro	66.3	93.0			Yang et al., 2023
CS/PEO 80/20	95.0	Electro	99.9	99.1	n/a	96.8	Arkoun et al., 2017
CS/PVA	84.2	Electro	90.0	85.3	n/a	n/a	Safari et al., 2025

Note: *, zone of inhibition. Abbreviations: CS = chitosan, PCL = polycaprolactone, PVA = polyvinyl alcohol, CMCS = carboxymethylated chitosan, qCS = quaternized chitosan, PVP = polyvinyl pyrrolidone, Fe_3O_4-CS = iron(II, III) oxide nanoparticle modified chitosan, and PEO = polyethylene oxide.

5.4.3. Antibacterial mechanism

The CS fiber exhibits antibacterial activity primarily via electrostatic interactions between its positively charged amino groups ($–NH_3$) and negatively charged bacterial cell membranes. The polycationic structure of CS attracts and binds to the anionic components (like teichoic acid) on the bacterial surface. This interaction disrupts cell wall integrity, causes intracellular leakage, chelates essential metal ions, and inhibits deoxyribonucleic acid (DNA)/ribonucleic acid (RNA) synthesis, leading to disruption of bacterial cell membranes or cell walls, causing leakage of intracellular components like proteins, DNA, RNA, or organelles, and ultimately death of cells, as shown in Fig. 10 (Gafri et al., 2018). A low MW CS can penetrate the bacterial cell and can interact with the DNA inside the cells, disrupting the synthesis of mRNA and proteins, causing cell death (Li and Zhuang, 2020). The antibacterial mechanism of qCS is similar to CS, but because of its better water-solubility, qCS can easily penetrate bacterial cells and, due to its higher positive charge, can better interact with negatively charged bacterial cell walls and also with its DNA, enhancing its antibacterial activity.

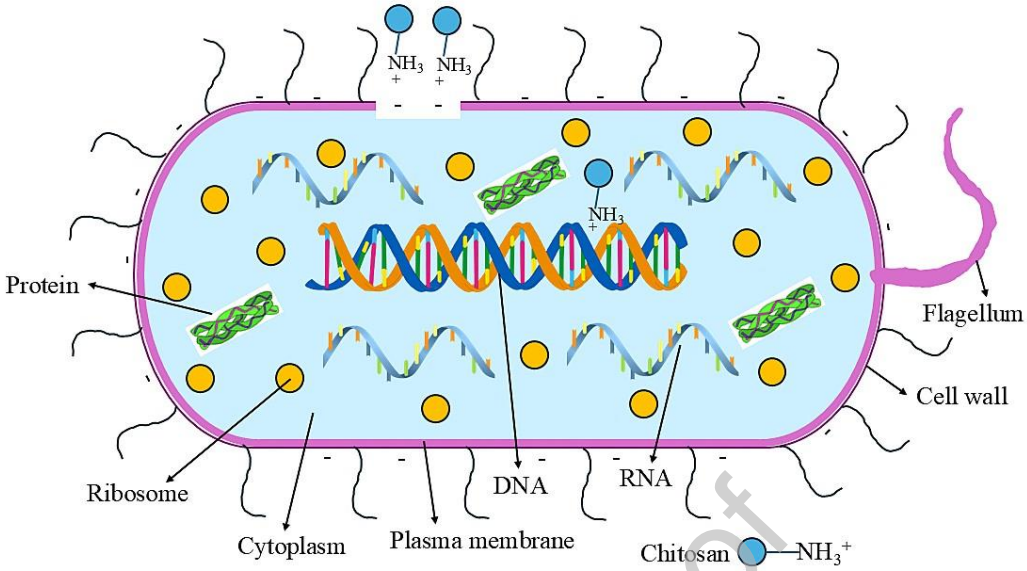


Fig. 10 Mechanisms of antibacterial activities of CS fiber (adapted from Gafri et al., 2018 with copyright permission from De Gruyter).

5.5. Stability of fibers in water

The stability of textile fibers in water is a critical property affecting the durability, appearance, and functionality of garments, and defines how a fabric will respond to laundering, sweating, and moisture-related environmental factors. The stability of fibers made from chitin in water is significantly better than that of fibers made from CS and other hydrophilic chitin derivatives. Effective techniques to enhance the hydrophobic character of fibers made from CS and other hydrophilic chitin derivatives may include chemical modification of their amine/hydroxyl groups through reacetylation, acylation, or alkylation (Cai et al., 2019). For example, CS fiber treated with acetic anhydride in aqueous acetic acid/ethanol mixtures showed better hydrophobicity due to the conversion of its hydrophilic free amino groups into hydrophobic acetamido groups (Hirano et al., 2000; Lavertu et al., 2012). By blocking hydrophilic amino or hydroxyl groups of CS fibers with hydrophobic acyl groups, the hydrophilicity of the fiber can be significantly reduced in aqueous environments (Wei et al., 2025). Reductive alkylation is a reliable method to introduce hydrophobic alkyl groups onto the C2-amine or C3/C6-hydroxyl groups, usually by employing a ketone or an aldehyde to produce an imine or Schiff base, and then reduction with sodium borohydride (Paula et al., 2020). These treatments may improve the hydrophobicity of chitin-derived fibers but will not make them water repellent.

6. Biodegradation and Toxicological Impacts

6.1. Biodegradation

The CS fiber is generally a highly biodegradable, biocompatible, and renewable material that decomposes through various degradation processes, including enzymatic hydrolysis (primarily by lysozyme), oxidative, and hydrolytic degradation (Pantaleone et al., 1992; Yang et al., 2007). However, crosslinking, chemical modifications, grafting, and additives used may impact their biodegradability. Chitin and CS fibers break down into natural metabolites like D-glucosamine and N-acetyl-D-glucosamine, with degradation rates highly dependent on the DD, MW, and environmental factors like humidity and pH of the environment. The CS fibers are broken down by microorganisms in soil and water environments, with accelerated degradation in compost-enriched soil. The decomposition of CS in soil and water environments is largely driven by microorganisms, such as bacteria and fungi, which utilize enzymes like chitosanase, lysozyme, and chitinases to break down the polymer chains. In compost-enriched environments, this degradation is accelerated due to higher microbial activity, often breaking down CS films in as little as 10–14 d (Oberlintner et al., 2021; Koumentakou et al., 2025).

6.2. Toxicological impacts

Chitin and its derivatives are generally considered safe and have low toxicity. As a natural cationic polysaccharide derived from crustacean chitin, its toxicity profile is low, with reported lethal dose (LD_{50}) values for CS-based materials often exceeding 16 g/kg in rats (Lagarto et al., 2015). The degradation products of chitin and CS, D-glucosamine and N-acetylglucosamine, both have quite low toxicity (Lee et al., 2004a). The use of CS as a dietary supplement on poultry, cattle, and swine showed no adverse effects, but rather showed various beneficial effects, such as antibacterial and anti-inflammatory activities (Boamah et al., 2023). Chitin and its various derivatives are also found beneficial for plant health as they can work as bio-fungicide, bio-bactericide, and bio-virucide (Li et al., 2013; Seberi Riseh et al., 2026). The CS-based bio-stimulants interact with soil microorganisms and function as natural soil conditioners and elicitors, stimulating their metabolic activity and fostering a more beneficial, diverse microbial community (Hahn et al., 2020). The CS nanoparticles and nanoparticles of chitin derivatives show cytotoxic effects on cancer cells while having minimal toxicity on normal cells (Siafaka et al., 2015; Huang et al., 2016; Liu et al., 2019). The CS can kill a range of bacteria but has only low-level effectiveness against fungi (Arslan et al., 2024).

7. Carbon Footprints

Carbon footprint studies are critical in the textile and fashion industry as this sector is envisaged as a major environmental polluter, contributing 6%–10% of global carbon emissions (Filho et al., 2022). Because of the fast fashion drive, the production volume of textiles has increased. It is necessary to identify the 'hotspots' in the supply chain, such as melt and dry spinning of synthetic fibers, and high-energy dyeing

and finishing, to reduce environmental impact and meet the United Nations' sustainable development goals. Table 3 presents the energy, water, and carbon footprints of various fibers. Of the nature-derived fibers, jute, sisal, and flax fibers have very low carbon footprints. Sisal has the lowest water footprint, 0.06–0.10 m^3/kg, but has a high energy footprint, 18.1 MJ/kg (Kahigi et al., 2025). Lyocell (regenerated cellulose made from wood pulp) has a low carbon footprint (3.2 kg CO_2e), but its energy footprint (54.3 MJ/kg) and water footprint (47.9 m^3/kg) are quite high (Alay et al., 2016). Jute fiber has a higher energy footprint compared to flax fiber, but a higher carbon footprint than flax fiber, still lower than that of several other natural fibers. The next best fiber in terms of carbon footprint is cotton, but its water footprint is moderately high. On the other hand, wool and silk fibers both have high energy and carbon footprints, but wool fiber has a low water footprint compared to silk fiber (Astudillo et al., 2014; Li et al., 2024). The CS fiber has a low carbon footprint (4.2 kg CO_2e), but its water (34.5 m^3/kg) and energy (302.4 MJ/kg) footprints are higher than those of many natural fibers due to the long extraction and purification processes (Muñoz et al., 2018; Vicente et al., 2024). They can be minimized by developing single-stage extraction, purification, and direct production of fibers from chitin. Considering carbon footprints, water and energy usage, still, CS fiber has a low environmental impact and can be a future feedstock for fiber production.

Table 3 Carbon footprint of various fibers

Fiber type	Carbon footprint (kg CO_2 e)	Energy usage (MJ/kg)	Water usage (m^3/kg)	Reference
Cotton	0.9–9.5	7.4–25.0	10.0–22.5	Yu and Yang, 2025
Flax	0.7–1.3	9.5–18.0	0.4	Dissanayake et al., 2009; Gomez-Campos et al., 2021
Silk	2.4–28.6	1467.0–1800.0	47.5–79.3	Astudillo et al., 2014; Dai et al., 2025
Jute	0.6–7.3	3.8–8.0	0.3–1.6	Singh et al., 2018
Wool	7.8–36.2	12.5–22.5	0.02–2.5	Wiedemann et al., 2016; Schmutz et al., 2021; Li et al., 2024
Lyocell	3.2	45.3	47.9	Alay et al., 2016
Sisal	12.8	18.1	0.05–0.1	Broeren et al., 2017; Wang et al., 2019; Kahigi et al., 2025
CS	4.2	302.4	34.5	Vicente et al., 2024

8. Key challenges and Future Directions

Chitin has the advantages of being abundantly available, bio-renewable, biodegradable, and bio-functional, and can be extracted from waste biomass. Although the very first development of chitin fibers was reported as early as 1926, the development and application of chitin-based fibers saw momentum only at the beginning of the 1990s. The advancements in processing techniques allowed for practical applications in medical textiles, wound dressings, and antibacterial textiles. Chitin-derived fibers are not widely used in the mass manufacturing of textiles because of the high cost of chitin and its derivatives (at least 50.0 yuan (USA) per kg), very low yield, and poor mechanical strength. Although a few published articles reported the production of high-strength CS fibers using a lab-based wet spinning set-up using a syringe pump instead of a laboratory wet-spinning machine (Li et al., 2012b; Chen et al., 2021), translating laboratory-

scale fiber performance into industrial production remains a critical challenge. Future studies must evaluate these technologies within a pilot-scale or industrial environment to validate their commercial viability. Because of the non-solubility of chitin in traditional solvents, fibers cannot be directly manufactured from it without derivatization, increasing the cost of production and also affecting the physicochemical properties of the resultant fibers, such as strength and durability to laundering due to the increased hydrophilicity. Economic and sustainable re-acetylation treatments will need to be developed for such fibers to enhance their launderability. Fibers made from chitin derivatives are weak, and even after crosslinking, their tensile strength is lower than that of the weak natural fibers (e.g., wool). The crosslinking of the fiber limits the increase in orientation and crystallinity enhancement by crosslinking in further processing, such as drawing. Its long-term durability can be affected by factors like the degree of deacetylation, molecular purity, and environmental conditions. The addition of other polymers (e.g., Cel) and additives (e.g., ChNF) can compensate for this weakness of fibers made from chitin derivatives. The use of ILs as a solvent made a huge improvement in the tensile strength of chitin/chitosan fiber and enabled direct spinning of chitin into fibers by gel/wet spinning without the deacetylation treatment. However, the cost of recycling ILs and difficulty in their complete removal from spun fibers (which affects their wet strength) hinder their practical application for industrial manufacturing of chitin and CS fibers. Most of the fiber production was studied mainly from CS, rather than other derivatives. For fiber production, hydrophobic derivatives of chitin with high MW need to be developed that are soluble in traditional solvents. Future research should also focus more on structure-property optimization of chitin fibers utilizing computational chemistry and manufacturing process optimization to achieve chitin fibers with the optimum strength for textile manufacturing.

Contamination from trace proteins and endotoxins has been shown to account for their allergic effect on human skin. Moreover, the production of fibers from shrimp- or crab-based chitin has very high energy and water usage. Conversely, fungal chitin has a very low carbon footprint compared to its traditional marine sources. With advancements in the extraction of chitin and optimization of manufacturing methods, chitin-based fibers are now commercially available for textile manufacturing. Omikenshi, a Japanese company, has commercialized ‘Crabyon fiber’ made from CS and Cel blends to offer high textile processability while retaining the antibacterial and skin-friendly features of pure CS. However, its production was discontinued for unknown reasons. Several Chinese manufacturers like Qingdao Yunzhou Biochemistry Co., Ltd., Fortune Cat® Fiber Factory, and Hismer Bio-Technology Co. produce wet-spun CS fiber for medical, apparel, and technical textiles.

Future directions in fiber production from chitin and its derivatives are heavily focused on enhancing sustainability, decreasing environmental impacts, improving mechanical strength, and durability to washing. Utilizing by-products of the seafood industry waste into high-value functional fibers contributes

to a circular bioeconomy. The development of conductive or responsive CS fibers for wearable sensors can transform wearable textiles into sustainable ones. For example, Wang et al. (2026) reported the production of a closed-loop recyclable and continuously processable core-shell type silver-plated nylon/CS-based triboelectric fiber using glycerol as a plasticizer for human movement tracking. The energy and water footprint of CS fiber production will also need to be considerably reduced by minimizing steps in chitin extraction from biomass.

9. Conclusions

Chitin and its various derivatives have immense possibilities for utilizing as a fiber-forming polymer to manufacture fibers for various applications, including textiles. The environmental impacts of fashion and textiles can be significantly reduced by decarbonizing textile fiber manufacturing by adopting cleaner production processes and switching to renewable and biodegradable feedstocks. This review article shows that chitin obtained from waste biomass can be an ideal feedstock for textile fiber manufacturing to achieve those goals. This review highlights the recent developments in the formation of textile fibers from chitin and its derivatives by various spinning methods. The effect of solvents used, addition of other polymers, additives, and crosslinking on the mechanical, functional, and microstructural properties is outlined. Besides chitin, various chitin derivatives, such as CS, CMCS, and BICS alone and with other additives (e.g., CelNF and ChNF), have been studied for fiber production. The wet spinning method is mostly utilized to produce fibers from chitin and its derivatives. A range of strategies, including physical (e.g., drawing) and chemical (e.g., crosslinking, blending with other polymers, addition of nanoparticles), were studied to enhance the wet strength and stability of fibers to a level. This review identified various obstacles for the industrial application of chitin as a sustainable feedstock in fiber manufacturing and proposed a few solutions. Current research is aggressively targeting the roadblocks to scaling chitin for fiber production by developing green processing techniques to lower extraction costs, optimize mechanical and functional properties, and transition to eco-friendly solvents to make the widespread adoption of this biopolymer economically viable. It can be anticipated that at least a portion of future textile fibers will be manufactured from chitin, which will also solve not only the disposal of a high volume of solid waste produced by the seafood industry, but also the disposal issues of post-consumer textiles.

Acknowledgements

This work was financially supported by the Natural Environment Research Council NERC of the UK Research and Innovation UKRI through the 'Future Fibers Networking' project (No. NE/Y003985/1).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author used no generative AI and AI-assisted technologies in the writing process.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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