

Chitosan Physical Forms: A Short Review

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Abstract: Chitosan is a modified carbohydrate polymer derived industrially by hydrolyzing the aminoacetyl groups of chitin. It is a natural, biodegradable, biocompatible, non-toxic, and anti-bacterial poly-saccharide available in different forms such as solution, powder, flake, fiber and film. Due to its wide range of physical forms, chitosan has broad applications in different fields. This paper reviews the latest development in the physical forms of chitosan and its blends. Various physical forms of chitosan and its blends together with other derivatives such as composites and graft copolymers have been developed to overcome its disadvantages such as poor mechanical properties and to improve its functionality towards specific applications. The progress made in converting chitosan and its blends into various physical forms as well as the preparation methods are presented.

Key words:

INTRODUCTION

Chitosan, a naturally occurring polysaccharide, is a cationic polysaccharide composed of [a 2-amino-2-deoxy- β -D-glucan] (Figure 1) obtained by the alkaline deacetylation of chitin. This chitin is present in shells of insects and marine crustacean such as shrimps and crabs. The unique properties of chitosan including availability, biodegradability, biocompatibility, bioactivity, non-toxicity as well as good adhesion and sorption are the major reasons for its multiple applications (Ravi, 2000; Pillai, 2001). Another main reason for this increasing interest of chitosan is its wide range of physical forms which can be obtained by using an appropriate technological process. Chitosan has already been used in a variety of fields such as wastewater treatment, medicine, agriculture, food, paper industry and cosmetics (Khor, 2003; Yuan, 2004; Crini, 2006; Li, 1992; Griesbach, 1999).

Due to the importance of the physical forms of chitosan in various fields of science and technology, this short review attempts to present the recent studies involved with chitosan as well as its blends in different physical forms. Finally the most important applications of the physical forms of chitosan and its blends in different fields are also depicted.

2. Physical Forms of Chitosan and its Blends (Preparation and Characterization):

Chitosan and its blends exist in various physical forms including resins, microspheres, hydrogels, membranes and fibers. The selection of one particular physical form depends mainly on the system configuration to be used for particular applications. The process of shaping chitosan blends into desired physical form starts from mixing the blend components in the liquid form and applying the appropriate shaping method. The preparation of various chitosan physical forms is summarized in Figure 2.

2.1. Resins (Beads)/microspheres:

Chitosan beads have been prepared by various methods, including solvent evaporation, coacervation and emulsion methods (Peniche, 2003; Genta, 1997). However, smaller and uniform beads can be obtained by the emulsion technique (Lim, 1997). The preparation of chitosan beads has also been reported by Bodemier *et al* (1989) and summarized by Srinatha *et al* (2008). Shortly, the cross-linking involves dissolving chitosan in acetic acid followed by stirring for 6-7 h. Then, known amount of ciprofloxacin HCl is added to the polymeric solution accompanied with stirring for 2 h. Dilute alkali solution is used for controlling the pH of the drug-chitosan solution at pH 4-4.5.

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After that, the drug-chitosan solution is added into sodium tripolyphosphate solution through a syringe. The formed beads are left for few minutes, collected by filtration, washed with distilled water and dried at 50°C for 4 h and then at room temperature (25°C) for 12 h.

Chitosan and its blends beads have been widely researched (Huguet, 1994; Polk, 1994; Liu, 1997; Dumitriu, 1998; Murata, 1999; Tomoaki, 2000; Gonzalez-Rodriguez, 2002; Murata, 2002). The chitosan/alginate microparticles (Kim, 1989; Kim, 1989b) chitosan/xanthan microspheres (Chellat, 2000a) and chitosan/gelatin microspheres (Yao, 1996; Yuji, 1996) have also been reported. A novel natural polymer chitosan/cellulose blend beads were prepared via homogeneous dissolution of chitosan and cellulose in methylmorpholine-N-oxide. The blend microspheres prepared by a spray-drying process have a spherical geometry and a smooth surface morphology (Twu, 2003).

2.2. Hydrogels:

Hydrogels of biopolymer is a significant class of polymeric materials due to their interesting properties for potential application in various fields such as biomedical, pharmaceutical and environmental industries. A number of procedures for preparing hydrogels from chitosan have been proposed in literature (Berger, 2004a; Berger, 2004b). The first step encompasses the process of dissolving chitosan in an organic solvent and the formation of emulsions or coacervates followed by cross-linking of the polymer (Koseva, 1999; Kumbar, 2002).

In the recent years, interest has been increased on modification of chitosan and its blends by crosslinking to improve the hydrogel stability. Non-covalent cross-linked chitosan hydrogel blends have been reported in the literature, such as chitosan/alginate (Takka and Acarturk, 1999), chitosan/carboxymethyl-cellulose (Arguelles-Monal, 1993; Fukuda, 1980) chitosan/dextran sulfate (Sakiyama, 2001) chitosan/carboxymethyl-dextran (Fukuda, 1978) chitosan/heparin (Kikuchi, 1976; Kratz, 1998) chitosan/carrageenan (Sakiyama, 1993) chitosan/pectin (Chang, 2000; Mireles, 1992) chitosan/collagen (Zhang, 1997) and chitosan/xanthan (Chellat, 2000b; Chu, 1995; Dumitriu, 1996; Dumitriu, 2000; Dumitriu, 1994; Ikeda, 1995). Crosslinking of chitosan hydrogel (Singh, 2006) and chitosan/PVA hydrogel membranes with formaldehyde (Yang, 2004) was also reported.

2.3. Films/membranes:

It is well known that chitosan can be easily made into films, especially by a casting technique (Kanke, 1989; Bonvin, 1993) which makes it useful for many applications including skin care, cosmetics, contact lenses, membranes and separators in various other technologies. Chitosan film properties have been reported by numerous authors (Butler, 1996; Chen, 1996; Singh, 1998; Bégin, 1999). Films of chitosan are clear, homogeneous and flexible with good oxygen barrier and mechanical properties (Hoagland, 1996; Kittur, 1998) but with relatively low water vapor barrier characteristics (Butler, 1996). In addition, films of chitosan are dense and do not possess pores (Muzzarelli, 1977; Hirano, 1982). Since chitosan degrades before melting, it is necessary to dissolve it in an appropriate solvent prior to casting into films.

The properties of chitosan films depend on their morphology, which is affected by the molecular weight (Butler, 1996; Chen, 1996) source of chitosan, degree of deacetylation, method of film preparation, free amine regenerating mechanism and most importantly by the type of dissolving solvent (Samuels, 1981; Lim, 1995). Acetic acid has been often used as a standard solvent for dissolving chitosan for film or membrane making. For example, Austin (Austin, 1982) reported chitosan films making from 5% w/v chitosan solution dissolved in 4% v/v aqueous acetic acid followed by coagulation in aqueous base solution. Averbach (1975) also reported casting chitosan films from 10% aqueous acetic acid solutions on stainless steel plates and drying them at 125°C. Casting chitosan from other acid solutions such as lactic acid yielded softer and more pliable bioadhesive films compared with those prepared from acetic acid (Khan, 2000).

Chitosan membranes prepared with various degrees of deacetylation of 75%, 87% and 96% (same molecular weight) were reported by Trung *et al* (2006). Membranes obtained from chitosan of higher degree of deacetylation exhibited higher tensile strength and higher elongation at break. In addition, membranes casted from chitosan with 75% degree of deacetylation displayed higher permeability and higher water absorption. Similar studies on chitosan membranes prepared from higher molecular weight chitosan showed higher tensile strength and percent elongation compared to those obtained from low molecular weight ones (Chen, 1996; Blair, 1987).

Elhefian *et al* (2009) reported the surface investigation of chitosan film with two fatty acids i.e., stearic (C18) and arachidic (C20) acids monolayers by means of Langmuir-Blodgett (LB) technique and atomic force microscopy (AFM). It was found that smoother and more homogeneous surfaces were achieved after transferring a layer of the fatty acids onto chitosan films.

The preparation of blend or composite chitosan films associated with other bipolymers has been repeatedly reported in literature. Blended films such as chitosan/pectin laminated films (Hoagland, 1996) chitosan/cellulose (Hasegawa, 1992) and chitosan/methylcellulose films (Kittur, 1998) were investigated and found to have improved properties compared to those of their pure components.

Similar films and membranes using blends of chitosan and synthetic polymers to improve the biocompatibility and expanded use as biomaterials were also reported in various occasions. For example, membranes prepared from blends of chitosan and polyvinyl alcohol (PVA) were investigated. The obtained membranes were found to be clear and homogeneous and have mechanical resistance greater than that of the pure components (Miya, 1983; Miya, 1984). Such membranes were capable of transport of halogenated ions and diffusion of cattle serum albumin (Uragami, 1983) and vitamin B12 (Nakatsuku, 1982) when crosslinked.

Nasir *et al.* (Mohd Nasir, 2005) reported preparation of chitosan and poly (ethylene oxide) blended membrane with various molecular weights in the range of 100,000 and 600,000 using solution cast technique. The addition of PEO with higher molecular weight was found to reduce the percentage of water adsorption of the obtained blended membranes whereas the addition of lower molecular weight PEO improved the porosity of chitosan as revealed by scanning electron microscopy. The results of structural analysis by x-ray diffraction showed that chitosan-PEO blended membrane with higher water adsorption ability has lesser degree of amorphosity. The blend membrane showed intermolecular interactions between chitosan and higher molecular PEO chains which caused an important alteration in chitosan structure and decreased the permeability of the membrane.

Elhefian *et al.* (2010) reported the preparation and characterization of chitosan/agar, chitosan/PVA and chitosan/agar/PVA blended films. The FTIR results, thermal curves and morphology showed that the interaction (intermolecular hydrogen bonding) among the functional groups of the blend components can occur.

2.4. Fibers:

Fiber is another physical form of chitosan, which was first reported as early as 1926 (Kunike, 1926). It possesses many advantages such as superior mechanical properties compared with the same material in bulk form. However, due to the high production cost, it was necessary for researchers to look into blends or composites of this polymer with other yarns. Fibers of chitosan blends have been frequently reported in literature. For instance, fibers of chitosan blends with collagen (Chen, 2006; Chen, 2008a) starch (Wang, 2007) poly(ethylene oxide) (Bhattarai, 2005) poly(vinyl alcohol) (Jia, 2007; Zhou, 2006) silk fibroin (Park, 2004) and alginate (Liao, 2005) have been reported.

Chitosan-poly (Lglutamic acid) and Chitosan-polyacrylic acid fiber are also reported in literature and showed potential for various applications in industrial applications due to their enhanced tensile strength and environmental biodegradability (Jaipura, 2006).

Electrospun nano fibers and nanofibrous structures of chitosan and its blends were reported in various occasions in recent years (Lertviriyasawat, 2008). For example, Chen *et al.* (2007) prepared collagen-chitosan complex nanofibers by electrospinning with a view to mimicking the native Extracellular Matrix (ECM) for tissue engineering and to develop functional biomaterials.

Nanofiber of chitosan/polyethylene oxide blends were made by high electrospinning for applications in air and water filtration (Desai, 2008). The introduction of an ultrahigh-molecular weight poly (ethylene oxide) into aqueous chitosan solutions remarkably enhanced the formation of nanofibrous structure and led to much lower loading of the water soluble fiber-forming aiding agent of PEO down to 5 wt % as compared to previous high PEO loadings in the electrospun chitosan nanofibers (Zhang, 2008).

The preparation of non-woven fibers by electrospinning blend solutions of chitosan and poly acrylamide with various blend ratios was also reported by Desai *et al.* (2008). The applications of chitin and chitosan (CS) nanofibers in these areas are reviewed by Pillai and Sharam (Pillai, 2009).

2.5. Sponge:

Sponge of chitosan based blends is of high interest in drug carrier systems. This is due to chitosan biodegradability, biocompatibility, antibacterial activity and non-toxicity of chitosan together with film forming capability. However, chitosan solutions cannot be foamed alone. Therefore, it is often combined with another good foaming polymer such as gelatin, which is also a cheap biodegradable polymer with good foaming properties (Poole, 1989). When blended with chitosan, gelatin makes a good contact with chitosan and forms polyionic complexes of slower rate of dissolution than chitosan at the appropriate pH value (Thacharodi, 1995). Such property could be utilized in drug release to a wound while the spongy form absorbs the wound fluid (Oungbho, 1997).

The release profile and biodegradability of both polymers can be effectively controlled by crosslinking (Tabata, 1989; Jameela, 1998). The release profile was found to be affected by the type of acid used during the preparation (Leffler, 2000).

Similar chitosan/alginate sponges were also studied in various occasions (Shapiro, 1997; Kofuji, 2001; Kataoka, 2001; Singla, 2001; Kumar, 2000; Coppi, 2002; Lai, 2003; Dai, 2003). For example, chitosan and sodium alginate blended sponge incorporating silver sulfadiazine was reported by Kim *et al.* (1999) for wound dressing application. Yang *et al.* (2001) also prepared hepatocyte-loaded alginate/galactosylated chitosan sponges for the growth of liver tissue.

Sponge of blended chitosan-fibroin that could be suitable for a future construction of dressing materials has been investigated by Strobin *et al.* (2006). It was found that chitosan/fibroin sponges reveal different structures of surface and cross-section depending upon composition. The sponges exerted reasonable strength and elasticity which gives a well grounded chance to use them for the construction of dressings.

3. Applications:

According to the literature, most of the applications of chitosan and its blends are in the pharmaceutical, biomedical and industrial fields depending on the type of the physical form. For example, chitosan beads have been receiving increasing interest in drug release applications. It has also been reported that chitosan beads are useful in heavy metals removal. Sponge of chitosan blends are also of current interest as wound dressing. Table 1 summarizes the applications of chitosan and its blends in different physical forms.

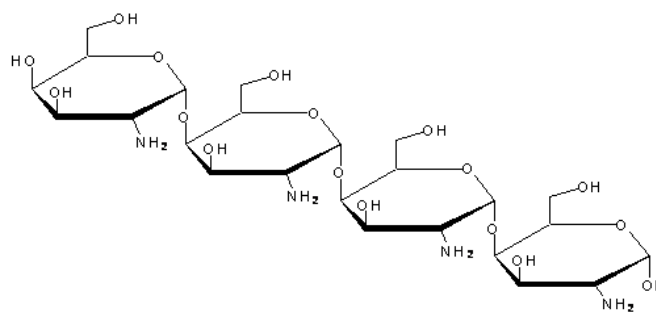


Fig. 1: Chemical structure of chitosan.

Table 1: Some applications of chitosan and its blends in different physical form.

Material	Physical form	Application	Ref
Chitosan/calcium phosphate composite	Fiber	Biomedical implant materials and drug carrier	(Matsuda, 2004)
Chitosan-poly (Lglutamic acid) and Chitosan-polyacrylic acid	Fiber	Industrial applications	(Jaipura, 2006)
Collagen-chitosan	Nanofibers	Tissue engineering	(Chen, 2007)
Chitosan-gelatin	Sponge	Biomedical applications (absorbs the wound fluid)	(Oungbho, 1997)
Chitosan /sodiumalginate + silver sulfadiazine	Sponge	Wound dressing application	(Kim, 1999)
Chitosan-fibroin blend	Sponge	Dressing materials	(Strobin, 2006)
Chitosan	Microspheres	Drug release	(Li, 1992)
Chitosan	Microspheres	Encapsulation	(Kosaraju, 2006)
Chitosan cross-linked with glutaraldehyde	Microspheres	Drug release	(Genta, 1998)
κ -carrageenan/chitosan	Membrane spherical capsules	Drug release	(Tomida, 1994)
Chitosan/carrageenan cross-linked with glutaric acid and glutaraldehyde	hydrogel beads	Drug release	(Piyakulawat, 2007)
Chitosan and chitosan-alginate	Beads	Removal of Cu(II) ions	(Wan Ngah, 2008)
Ionic cross-linked chitosan	Beads	Drug release	(Shu, 2002)
cross-linked chitosan-alginate	Beads	Drug release	(Anal, 2005)
chitosan and cross-linked chitosan beads	Beads	Removal of Cu(II) ions	
Ionically and chemically cross-linked chitosan	Beads	Remove the anionic dyes	(Chiou, 2004)
Glutaraldehyde-activated alginate-chitosan	Gel beads	Immobilization of antibodies	(Albarghouthi, 2000)
Chitosan flakes and cross-linked chitosan beads with glutaraldehyde	Flakes and beads	Adsorption of p-nitrophenol	(Wan Ngah, 2006)

Table 1: Continue

Chitosan and cross-linked chitosan beads with glutaraldehyde (GLA), epichlorohydrin (ECH) and ethylene glycol diglycidylethe	Beads	Adsorption of Fe(II) and Fe(III) ions	(Wan Ngah, 2005)
Chitosan cross-linked with sodium tripolyphosphate	Beads	Drug release	(Srinatha, 2008)
Chitosan	Beads	Color removal	(Wu, 2001)
Chitosan	Hydrogel beads	Adsorption of nitrate	(Chatterjee, 2009)
Chitosan	Beads	Drug release	(Sezer, 1995)
Chitosan	Hydrogel beads	Fulvic acid adsorption	(Wang, 2008)
Chitosan	Beads	Sorption of Cr(VI)	(Kousalyaa, 2010)
Chitosan	Porous beads	Cu (II) ion adsorption	(Zhao, 2007)
Chitosan	Hydrogel beads	Encapsulate proteins.	(Alsarra, 2004)
Chitosan	Hydrogel beads	Fulvic acid removal	(Sun, 2008)

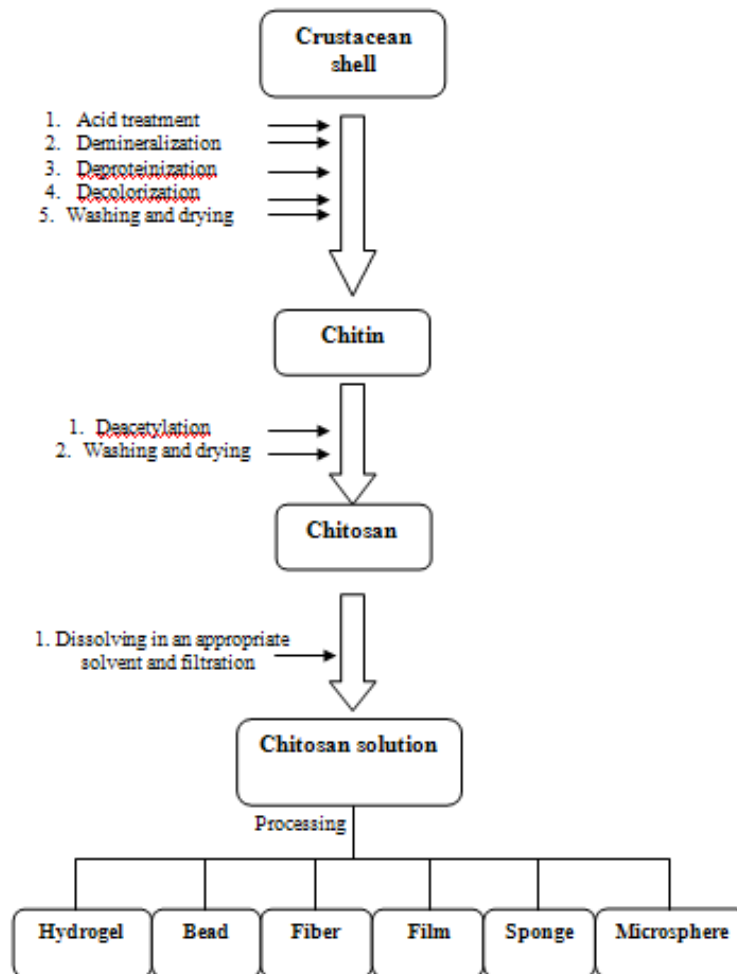


Fig. 2: Routes for preparation of various chitosan physical forms.

Conclusions:

Due to the importance of chitosan forms in several fields, this brief review has attempted to shortly describe the recent studies on the physical forms of chitosan and its blends. It also focuses on the most important application of chitosan blends. These studies clearly revealed the strong relation between the physical form and application.

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