Biomedical Applications of Chitin, Chitosan, Their Derivatives, and Processing By-Products from Fish Waste

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Abstract The use of natural resources has increased by 254% from 1970 to 2017 globally. Similarly, the consumption of fish and fish products has also gained popularity over the last few years. As per available records and data, it has been projected that about 75% of the fish biomass is discarded as biological waste which can be explored, recycled, and processed for further validation. Fish waste as a rich source of enzymes, bioactive peptides, polymers, and many other bioactive compounds has been studied by several researchers in the last decades. In this chapter, we would focus only on chitin, chitosan, its derivatives, and processing by-products in advanced applications dimensions. They have a huge potential for use in the field of biomedical engineering, and in this article, we will concentrate on their usage in the areas of growth factor delivery, cancer diagnostics, cartilage and tendon repair, dentistry, drug administration, gene delivery, and bone tissue creation. Besides, they have also got used in food and cosmetic industries, nutraceuticals, and bioremediation.

Keywords Chitin · Chitosan · Fish waste · Biomedical applications

1 Introduction

Recent significant increases in several diseases concluding cardiovascular system, the change in lifestyle and food habits are the major advised prescription. As a part of this, the consumption of fish and fish products have been increased dramatically (Coppola et al. 2021; FAO 2018). As a result of it, the fish byproduct and biomass have also increased which environmentally, socially, and economically can best be utilized

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S. Maqsood et al. (eds.), *Fish Waste to Valuable Products*, Sustainable Materials and Technology, https://doi.org/10.1007/978-981-99-8593-7_12

with effective fish waste management strategies (Ferraro et al. 2010; Mo et al. 2018). Among the by-products of the fish industry, different important bioactive and valuable components have been reviewed for use in the biomedical and pharmaceutical fields like enzymes, chitin, polyunsaturated fatty acids, minerals, collagen, peptides, etc. (Shahidi et al. 2019; Shavandi et al. 2019).

In this chapter, we would exclusively discuss only on chitin, chitosan, and their derivatives in advanced application dimensions. Because they are natural biopolymers, chitin and chitosan are non-toxic, biocompatible, and biodegradable. Chitosan is a chitin derivative produced by deacetylating chitin through enzymatic hydrolysis. They can be used to make a variety of forms, such as membranes, gels, nanoparticles, microparticles, nanofibers, beads, scaffolds, and sponges.

Chitin, which is the second most prevalent polymer after cellulose and is a white, nonelastic, rigid, nitrogenous polymer of natural origin, was first discovered in 1884. It is a part of the exoskeleton of arthropods and a component of yeast and fungi's cell walls. Chitosan, which is produced by enzymatic hydrolysis or deacetylation, is the primary chitin derivative. Although it cannot be dissolved in water or organic solvents, it can be dissolved in a variety of acids, such as acetic, hydrochloric, nitric, and perchloric (Rinaudo 2006; Sankararamakrishnan and Sanghi 2006; Kurita 2006). Chitosan has an electrically positive charge and is hence able to adhere to negatively charged surfaces. As the cell surface is anionic, chitosan is believed to adhere, due to electrostatic interactions (Dash et al. 2011). Three different group types in chitosan make it possible to produce copolymerized components specifically for use in tissue engineering. Different modified chitosan can be created with various targeted effects depending on the level of deacetylation (DDA) and molecular weight (MW). Researchers have created a variety of chitin and chitosan composites that have shown to be future attractive candidates in the biomedical fields.

2 Chitosan Processing

The following steps (Fig. 1) are maintained for yielding chitosan (Rinaudo 2006; Roberts 1992).

Based on the source the extraction process varies. The traditional extraction process involves steps like demineralization, deproteination, bleaching, and deacetylation.

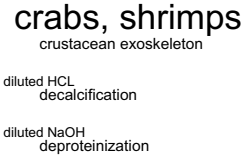

Fig. 1 Processing of Chitosan

3 Chitin/Chitosan from Aquatic Ecosystem

Chitin may be isolated from shrimps, crabs, lobsters, and crayfish in the form of granules, sheets, and powders (Khor and Lim 2003; Khor 2014; Ehrlich et al. xxxx). Chitin has also been isolated from sponges and found to be effective in biomedical engineering (Ehrlich et al. 2007; Brunner et al. 2009a, 2009b). Chitin is been documented to be obtained from protozoa or alga, foraminifera (Jeuniaux and Voss-Foucart 1991). Diatoms, hydroids, coelenterates, brachiopods, polychaetes, pogonophorans, mollusks, and crustaceans have also been documented to yield chitin (Kurita 2006; Brunner et al. 2009a). The shell of all crabs and shrimps has been enlisted to provide the α-chitin (Stepnowski et al. 2004).

4 Different Composite of Chitin and Chitosan

Base	Composite and type	Reference
Chitin	The sponge-like 3D chitin	Kim et al. 2008; Rinaudo 2008; Abe et al. 2004)
Chitin	Electrospun water-soluble carboxymethyl	Menon et al. xxxx)
Chitin	Fiber	Mikhailov et al. 2001)
Chitin	Electrospun transparent nano mats	Shamshina et al. 2018)
Chitosan	Heparin-like composite fibrous membranes	Li et al. 2018)
Chitosan	Nanofibers with carbon nanotubes, Fe_3O_4, and TiO_2	Bahmani et al. 2020)
Chitosan	Cellulose chitosan multifilament fiber	Zhu et al. 2019)
Chitosan	Films and membranes	Hu et al. 2016; Youssef et al. 2016)
Chitin	Cellulose hydrogels	Shamshina et al. 2014)
Chitin	MCC aerogels	Shen et al. 2016)
Chitosan	CMC and Glycerol 2 phosphate hydrogels	Azadi et al. 2018)
Chitosan	Hydroxypropylmethylcellulose and glycerol thermosensitive hydrogel	Wang et al. 2016)
Chitosan	Cellulose hydrogel	Kabir et al. 2018)

Biomedical applications in the area of.

1. *Bone Tissue Engineering*

For effective bone tissue engineering, any implant/scaffold must be biocompatible, biodegradable, and bioactive. Chitin and chitosan along with these properties also possess flexibility and porosity, but they lack mechanical strength and are unstable too (Mathur and Narang 1990). Hence different composites of chitin and

chitosan have evolved to mitigate the disadvantages and have been used in bone tissue engineering. Enhancement of mechanical strength with different composites like alginate for resisting compressive force (Li et al. 2005) and poly(lactic-co-glycolic)acid(PLAGA) (Jiang et al. 2006) composite was investigated with promising results. Further in one study the efficacy of heparin-modified chitosan-PLGA scaffold and recombinant human bone morphogenic protein (rhBMP-2)-heparin chitosan-PLGA scaffold was investigated for osteointegration, osteoblastic proliferation, and differentiation, and rapid bone formation with a promising result (Jiang et al. 2010). Additionally, different composites have also been examined in bone tissue engineering like arginine–glycine–aspartic acid conjugated UV-cross-linked chitosan (Tsai et al. 2012), poly-caprolactone-chitosan scaffolds (Wu et al. 2010; Thuaksuban et al. 2011), growth factors releasing porous poly-caprolactone-chitosan scaffolds (Im et al. 2003), bone morphogenic protein-2 and 7 incorporated chitosan scaffold (Yilgor et al. 2009), chitosan-collagen scaffold incorporated with rhBMP-2-PLGA (Shi et al. 2009), chitosan scaffold functionalized with heparin (Gümüşderelioğlu and Aday 2011). In one study poly L Lactic acid-chitosan scaffold was soaked in Ca^{2+} and PO_4^{3-} solutions for increasing the osteoconductive properties of this scaffold and the same was investigated to facilitate bone regeneration (Prabaharan et al. 2007). All of the above studies yield better results in terms of maintaining scaffold porosity, increasing osteoconductivity, improving mechanical attributes, reducing the rate of degradation of materials, and finally augmenting bone formation.

Apart from this, nano-hydroxyapatite (nHAp), being osteoinductive and conductive, also have been investigated by incorporating chitin (Chang et al. 2013). Similarly, the incorporation of nHAp with α-chitin and β-chitin, chitosan hydrogels for bone tissue engineering is investigated (Kumar et al. 2011; Sudheesh Kumar et al. 2011; Madhumathi et al. 2009). Studies on HAp-incorporated chitin and chitosan, different polymeric and ceramic-like silk fibroin, carboxymethyl cellulose, gelatin, and carbon nanotube-incorporated chitin and chitosan have been reviewed and found to have improved mechanical strength with better and uniform mineralization (Fig. 2) (Li et al. 2006; Frohbergh et al. 2012). Osteoblast obtained from mesenchymal stem cells was seeded into a HAp-chitin scaffold and was studied for osteogenic properties (Ge et al. 2004). Similarly, goat mesenchymal stem cells were also studied in chitin composite for new bone tissue regeneration with good results (Liu et al. 2010). Reports on bioactive glass (BGC)-chitin/chitosan composite for use in load-bearing areas including nanocomposite, nano-silvers, solvent cast bioactive glass, the hybrid scaffold of Bioactive glass, surface modified BGC is recorded for better mechanical strength, biocompatibility in the bone and dentistry (EBSCOhost xxxx; Hench et al. 1971; Jones 2013). Hybrid Chitin/chitosan-silica/titania and zirconia composite for bone formation and regeneration is also demonstrated by different researchers (Toskas et al. 2013; Jongwattanapisan et al. 2011).

2. *Cartilage Repair*

Most of the time cartilage damage demands surgical interventions especially replacement owing to the fact of degenerative changes that may occur due to disease, trauma, or genetic irregularities. Conventional surgeries do not guarantee all the time

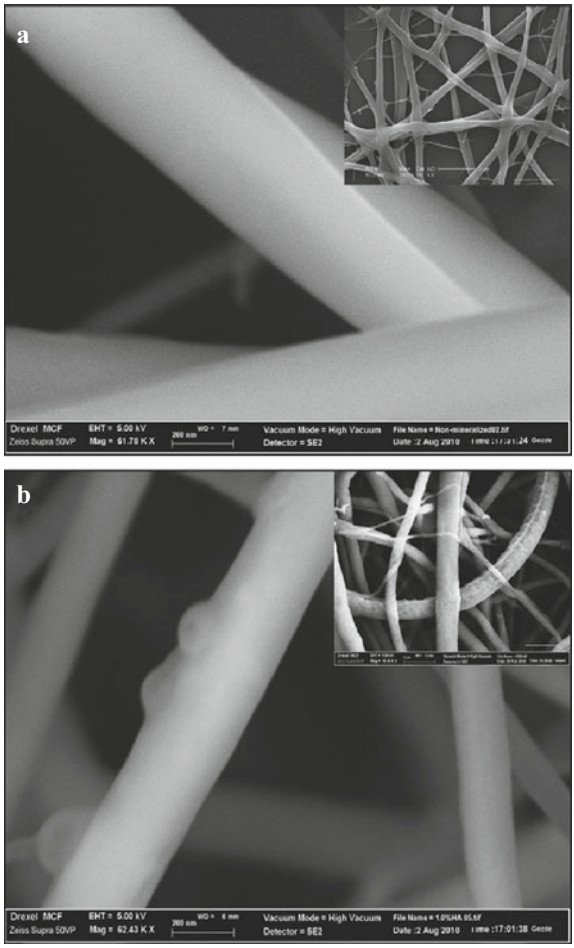

Fig. 2 Examination of electrospun scaffolds morphology by atomic force and scanning electron microscopy. SEM images of chitosan nanofibers with 7% HA content and 0.1% genipin cross-linked CTS-GP **a** and 0.1% genipin cross-linked 1.0% GP **b** show distinctive nanofiber shapes at low magnification. (**Reproduced from Biomaterials Journal, Frohbergh, et al., 2012, with permission**)

a scarless operative site and hence suffer from loss of mobility and reduced functionality. Here lies the need for a cell scaffold composite that can stimulate, regenerate, and remain active in the scaffold environment. Chitosan has been found to have chondrogenesis properties. Porcine chondrocyte-seeded chitosan scaffold was studied with a positive outcome for chondrogenesis (Use and of Chitosan as a Cell Scaffold Material for Cartilage Tissue Engineering xxxx; Griffon et al. 2006). Chitosan microspheres incorporated with transforming growth factor β showed improved chondrocyte growth (Kim et al. 2003; Lee et al. 2004). Chitosan-collagen-genipin scaffold demonstrated better viability of chondrocytes in rabbits (Yan et al. 2010). Utilizing the hemostatic characteristic of chitosan composite in cartilage regeneration resulted in the development of hyaline cartilage and the variation of pluripotent cells into chondrocytes (Hoemann et al. 2007; Hao et al. 2010). Chitin and chitosan hydrogels showed significant achievement in terms of regeneration of damaged cartilage and

wound healing (Xi et al. 1999; Jin et al. 2009; Tan et al. 2009). Different hydrogel composite of chitosan is demonstrated to provide better chondrocyte survival (Park et al. 2013). The chitosan-based fibrous scaffold has been studied with better deposition of the extracellular matrix (Subramanian et al. 2004). The hybrid scaffold of chitosan was evaluated for the mechanical integrity of cartilage formation (Neves et al. 2011).

3. *Tendon and Ligament Repair*

As with cartilage, tendon and ligament repair also have drawbacks of scar tissue formation. For any technology to be used in the repair process must meet high tensile strength along with regenerative capacity. A polyelectrolyte complex of alginate-chitosan gave better adhesion attributes (Majima et al. 2005). Similar findings along with enhanced strength were found in the hyaluronic acid chitosan complex (Funakoshi et al. 2005a). Other studies using hyaluronic acid chitosan complexes with osteoblast seeds also produced results that were more favorable in terms of increased mechanical strength (Fig. 3) (Funakoshi et al. 2005b; Irie et al. 2011). As chitin is degraded first, hence alone chitin fabric sometimes gave poor regeneration of non-healed ligament with evidence of scar tissue, but if a composite is formed with PCL the outcome was found to be encouraging (Funakoshi et al. 2006; Sato et al. 2000). The role of chitosan in treating ligament injury lies in favoring the deposition of collagen type I (Tendon healing in vivo and in vitro: chitosan improves range of motion after flexor tendon repair 2013). Similar studies were also carried out by other scientists indicating the outcome at per (Shao et al. 2010a, 2010b).

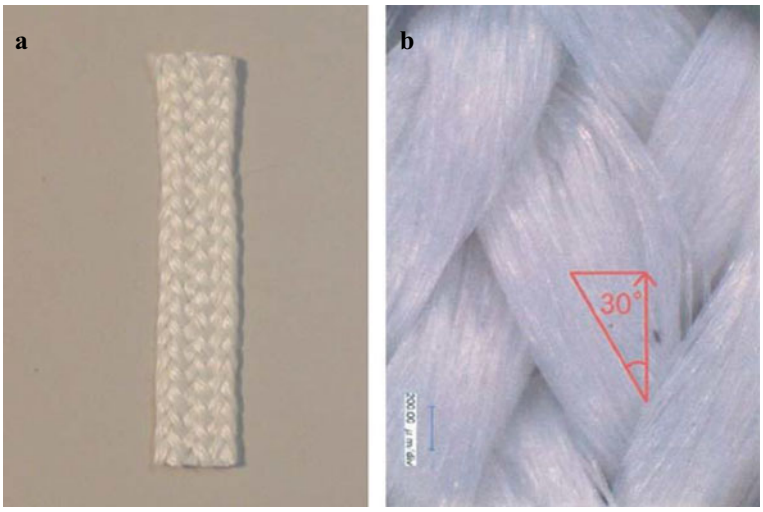

Fig. 3 **a** A braiding machine was used to produce a three-dimensional scaffold from 13 braids that measured 40 mm long, 7 mm broad, and 0.7 mm thick. **b** The braided fibers and longitudinal axis formed a 30-degree angle. (**Reproduced from J. Biomed. Mater. Res. A Irie et al., 2010 with permission**)

4. *Skin Regeneration*

As already discussed the hemostatic properties of chitin and chitosan, may be well employed for the healing of varied types of dermatological conditions (Taravel and Domard 1995, 1996; Ma et al. 2001). Cotton fiber type chitosan with rapid healing and presence of polymorphonuclear cells (Ueno et al. 1999), growth factor incorporated chitosan with better healing (Mizuno et al. 2003), chitosan-alginate polyelectrolyte complex with better wound stability (Yan et al. 2000; Wang et al. 2002), chitosan-collagen scaffold providing more fibroblast infiltration (Ma et al. 2003), chitosan acetate bandaging with improved antibacterial and anti-inflammatory property (Burkatovskaya et al. 2008), growth factor incorporated collagen-chitosan complex in burn wound with enhanced neo-angiogenesis (Guo et al. 2011), atelocollagen-chitosan in excisional wound healing198, chitosan hydrogels for skin tissue healing (Kumar et al. 2013) have been investigated and documented for ease of ready to hand reference.

5. *Liver Regeneration*

As the liver's extracellular matrix contains glycosaminoglycans, hence chitin and chitosan are used in different hepatic engineering and regeneration because these glycosaminoglycans are also a part of chitin and chitosan (Li et al. 2003a) and have been recorded to modulate the actions of vascular endothelial cells (Chupa et al. 2000). Different composites along with their applications have been listed below.

Composites	Application	References
Chitosan-collagen	Increased hepatocyte compatibility	Wang et al. 2003)
Chitosan-collagen-heparin	Artificial liver with more blood compatibility	Wang et al. 2005)
Chitosan-galactose	Increased hepatocyte attachment	Park et al. 2003)
Chitosan-fructose	Increased liver cell metabolic activities	Li et al. 2003a; Li et al. 2003b)
Chitosan-fibroin	Increased hepatocyte attachment	She et al. 2009)
Chitosan-galactosylated hydroxyapatite	More albumin secretion and elimination of urea	Fan et al. 2010)
Chitosan-poly ether-ether ketone	The proliferation of progenitor cells	Piscioneri et al. 2011)

6. *Nerve Regeneration*

Peripheral nerve regeneration and repair frequently involve chitin and chitosan. Schwann cell, one of the key cells in nerve tissue engineering showed better migration, adhesion, and proliferation with chitosan fiber (Yuan et al. 2004). The effectiveness of the chitosan complex in additional research on cell adhesion, proliferation,

and migration has been evaluated (Cao et al. 2005; Mingyu et al. 2004; Cheng et al. 2003; Chiono et al. 2008). The viability and proliferation of different neural cells were studied in chitosan-collagen composite (Yang et al. 2010) and laminin-coated chitosan membrane (Guo et al. 2012).

5 Application in the Field of the Delivery System

Any kind of regeneration, repair, and healing is always associated with growth factors and can be influenced by different drugs and gene therapy. In these domains, chitin and chitosan are crucial. Here we will briefly review the effect of these in tabular form.

Different drug delivery implant has been prepared like chitosan scaffold for 5-Fluorouracil (Denkbaş et al. 2000), chitosan-pectin cross-linked scaffold with pentoxifylline incorporated films (Lin and Yeh 2010a), pentoxifylline loaded chitosan-alginate scaffold (Lin and Yeh 2010b), ketoprofen loaded Chitosan-carboxymethyl β–CD (Prabaharan and Jayakumar 2009), ampicillin-loaded alginate microspheres in chitosan-nano-hydroxyapatite scaffolds (Shi et al. 2007), dexamethasone impregnated Chitosan scaffold (Duarte et al. 2009), tetracycline loaded chitosan-hydroxyapatite scaffolds (Teng et al. 2009), amikacin and vancomycin loaded chitosan sponge (Noel et al. 2010), collagen-chitosan for transdermal drug delivery (Thacharodi and Panduranga Rao 1996), vitamin B2 as a model drug in glucose-cross-linked N-alkylated chitosan membranes (Li et al. 2002), nifedipine incorporated chitosan membrane (Thacharodi and Rao 1993), collagen-chitosan as a carrier of propranolol (Thacharodi and Panduranga Rao 1995) and the results demonstrated better release, stability with lowered enzymatic degradation. Carboxymethyl chitin has also been used for drug delivery (Jayakumar et al. 2010).

Besides, the delivery of growth factors may be attributed to chitin and chitosan. The incorporation of bFGF into chitosan was in periodontal regeneration (Tığlı et al. 2009). bFGF was also incorporated in chitosan-alginate scaffold and found to be a potential carrier system for tissue repair and regeneration (Ho et al. 2009). Chitosan microsphere scaffolds have been used for the evaluation of carriers of ALP and BMP-2 (Reves et al. 2009). CS composite has also been used for the delivery of VEGF for hard tissue regeneration (Riva et al. 2010). The administration of rhBMP-2 for bone regeneration has been successfully shown using the chitosan-collagen scaffold (Shi et al. 2009).

Chitosan-based DNA/siRNA complexes sometimes have the problem of early and immature release of nucleic acids (Buyens et al. 2012) and less penetration to cells. Hence, complexes with improved performances have been investigated with promising results. Enhanced cell penetration has been achieved by surface modifications of chitosan by ligands like transferrin (Mao et al. 2001; Chan et al. 2007), folate (Kim et al. 2006), mannose (Gao et al. 2003), and galactose (Gao et al. 2003; Park et al. 2001) have yielded good results. For increased stability, chitosan has been modified by Quaternization (Kean et al. 2005; Thanou et al. 2002), glycosylation

(Thanou et al. 2002; Strand et al. 2008), and hydrophobic modification (Lee et al. 2012). Fusogenic peptides and pH-sensitive neutral lipids have been added to several research projects to improve DNA/siRNA. Plans to mute RANK signaling utilizing chitosan hydrogel as a siRNA reservoir and vector have also been examined (Kang et al. 2017).

6 Application in Wound Healing

Chitin and different composite membranes have been tested from the perspective of wound healing and found to possess excellent biocompatibility, minimal or less tissue reaction, and regenerative and antibacterial properties (Singh et al. 2008; Azad et al. 2004). Similar results were also obtained with chitosan membrane (Santos et al. 2013), chitosan composites (Pang et al. 2008), silver sulfadiazine incorporated chitosan alone (Mi et al. 2003), and chitosan-alginate composite (Meng et al. 2010), argon plasma treated chitosan membranes in fibroplasia (Zhu et al. 2005). Different wound dressing materials based on chitosan hydrogel composite gave excellent results (Queiroz et al. 2003). Porous chitosan membrane proved to possess good hemostatic as well as excellent epithelialization properties (Mi et al. 2001). The different composite sheets of chitosan (Wang et al. 2012), diverse sponges of it (Lee et al. 2000), and composite bandages in non-cytotoxic in nature (Sudheesh Kumar et al. 2012). According to all of the aforementioned studies, chitin and chitosan, as well as their composites, have excellent bioacceptability, good regenerative properties, epithelialization, hemostasis, adhesion, stability, antibacterial and anti-inflammatory properties, and, most importantly, have improved wound healing.

7 Application in Cancer Diagnosis

Chitin and chitosan are frequently employed in the diagnosis and treatment of cancer among other purported biological purposes. In cancer imaging heavy metal-free luminescent zinc sulfide (ZnS) is considered bio-friendly to healthy and cancer cells over the use of heavy metal-containing nanocrystals such as cadmium sulfide, cadmium selenide, and zinc selenide (Derfus et al. 2004). However, in an in-vitro study chitosan encapsulated ZnS nanoparticle is used in cancer imaging (Higuchi et al. 2008) and the study shows the yield of mannosylated ZnS of size 120 nm after functionalizing with D-Mannose and its low cytotoxicity toward healthy and cancer cells. Moreover, its specificity of the binding property toward mannose-bearing KB cells under fluorescence microscopy encourages receptor-mediated imaging with nanoparticles as well as in cancer therapy (Higuchi et al. 2008).

The report of various researchers from across the world clearly demonstrates the importance of chitin and chitosan as therapeutic agent in cancer biology through the direct death of malignant cell lines and as a vehicle for anticancer medication

delivery systems. Chitosan's anti-cancerous properties are mostly attributed to the maturation and infiltration of cytolytic T-lymphocytes via enhanced interleukin-1 and interleukin-2 production (Lin et al. 2007). Some researchers have shown anticancer efficacy through the direct destruction of tumor cells by triggering apoptosis (Gibot et al. 2015).

Chitin inhibits an elevated serum level of proinflammatory mediators chitinase-3 like protein-1 (CHI3L1) in breast cancer, colorectal cancer, ovarian cancer, leukemia, lymphoma, metastatic prostate cancer, lung cancer, and glioblastoma by blocking the synthesis of vascular endothelial growth factor C. (VEGF-C). Additionally, other forms of chitin, such as chitin-glucan-aldehyde-quercetin conjugation and silver-embedded chitin nanocomposites, exhibit biocompatible cytotoxicity in human breast cancer (MCF-7) cells (Solairaj et al. 2017) and in macrophage cancer cell line (J774) respectively (Singh et al. 2018). Further, in the drug delivery system doxorubicin coated with chitin-based poly L lactic acid composite nano gel and ellagic acid in chitin nanoparticle shows cytotoxic effect in the liver (Arunraj et al. 2014) and breast (Pirzadeh-Naeeni et al. 2020) carcinoma respectively. Similarly, chitin, chitosan, and chitosan oligosaccharides are also used in cancer therapy. A 2015 study by Gibot et al. found that the apoptotic impact increased in RPMI7951 cells, cell proliferation decreased in SKMEL38 cells, and cell adhesion quality decreased in A 375 cells (Gibot et al. 2015). Moreover, chitosan oligosaccharide in colorectal cancer abolished tumor progression (Mattaveewong et al. 2016), and modulated cell autophagy in the A549 lung cancer cell line in oral squamous cell carcinoma producing the cytotoxic effect by arresting cell cycle and apoptosis without any adverse effect on adjacent noncancerous cells (Wimardhani et al. 2014). This chitosan also shows anti-cancerouse effects in liver carcinoma in mice (Jiang et al. 2015), and lung cancer A549 cell line (Gao et al. 2020). In lung cancer, the A549 cell line chitosan selenate shows its potent activity in the apoptosis of cancer cells. In addition, many chitosan nanoparticles are employed in anti-cancerous drug delivery systems, including chitosan oligosaccharide conjugated to 5-fluorouracil and vanillin, chitosan oligosaccharide conjugated to indomethacin, and chitosan graphene oxide attached to thioguanine (Hasanzade and Raissi 2019; Lee et al. 2017; Li et al. 2016).

8 Application in Dentistry

Chitosan is been widely studied in dental engineering for its biocompatibility, non-toxicity, biodegradability, and antimicrobial activities. Apart from that, it has the property to form film and gel which is very helpful for application in the dental field (Fiorillo 2019; Husain et al. 2017). Chitosan has widely been used for caries prevention as well as in conservative dentistry (Ortiz and Boyce 2008). One remarkable study report denotes better periodontal health and condition with chitosan brushing (Zeza et al. 2017). Chitosan has also been proven to reduce the bleeding time after the extraction of teeth (Pippi et al. 2017). It has been investigated for anti-inflammatory

and pain relief properties with significant outcomes in dental affection and engineering (Lope-Lopez et al. 2015). Chitosan also proved to combat demineralization in dental affection cases (Uysal et al. 2011). The form of toothpaste of chitosan has been used to reduce the oral bacterial count (Mohire and Yadav 2010).

9 Other Applications of Chitin and Chitosan Apart from Biomedical Spheres

Chitin and chitosan are employed in a variety of industries, including food and cosmetics, nutraceuticals, water treatment, and bioremediation, in addition to biomedicine. The usage of chitin and chitosan in bioremediation is significant due to the conversion of contaminants and interaction with heavy metals and removal in an aqueous solution (Hayes et al. 2008; Barriada et al. 2007). Papayafish scale collagen has been found to have iron-clearing properties from groundwater (Irawan et al. 2018). Chitin and chitosan are utilized in the food industry as food additives and have also been included in food packaging materials because of their antioxidant and antibacterial properties. Silver thiosulfate and actinides are two industrial pollutants that have been treated using chitin-based biomaterials (Kosyakov et al. 2002). Chitin has also been used in the paper industry for increasing strength.

10 Conclusion and Future Scope

Fish processing is now becoming a major industry in many countries and fish by-products are being widely used in many sectors including biomedical applications. The vast source of collagen, proteins, oils, chitin, and chitosan is derived from the fish industry. The encouraging biomedical applications of chitin and chitosan have attracted the attention of researchers to explore their use in a more intensive and easier application, as well as making the research into a new dimension for application in biomedical spheres. Still, the user has yet to be investigated in light of biocompatibility, degradability, acceptability, and bioactivity. Further, the research program should be oriented to develop composites of chitin and chitosan more fruitfully in various biomedical applications. The same has to reach the hand of clinicians at a reachable price. The research should be aimed to transfer from laboratories to clinics.

Acknowledgements The vice chancellor of West Bengal University of Animal and Fishery Sciences, in Kolkata, India, is gratefully acknowledged by the authors. The authors also acknowledge the kind support of the ICAR National Professor project of the Indian Council of Agricultural Research, New Delhi.

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