Chapter 1

Introductory Chapter: Multitask Portfolio of Chitin/Chitosan: Biomatrix to Quantum Dot

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Additional information is available at the end of the chapter

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1. Introduction

Rational designing of novel materials has addressed diverse technical needs and industrial problems in addition to their own sizeable share in the prosperity of modern sciences. Biomolecule/polymer yields from natural sources like fungi, bacteria, animals and plants is fascinating due to the innate endurance of the environment and life [1]. Hence, scientists have searched many natural polysaccharides and biopolymers, including agar, algin, carrageenan, glycogen, glycan, pectin and chitin, because of their embryonic/innovative potential to cater for futuristic demands in science and technology (S&T) [1, 2].

In this regard, natural polymers/biopolymers and biomaterials can provide all such aspiring demands for current advances in scientific development. Hence, the scope of this book is targeted precisely, with a concise introductory chapter on the multitask portfolio of chitin/chitosan from biomatrix to quantum dot. The uniqueness of this book is prevalent in all the chapters, which ensure the utmost coherence and relatedness to vital issues allied to the material chemistry of chitin/chitosan, in addition to offering a true analysis of the challenges currently faced by the scientific community in material sciences. The book provides a motivating theoretical and diagnostic R&D framework, and readers will be able to easily understand its contents as well as examine its research claims. In fact, the outcome of this book will hopefully manifest the unequivocal multitask portfolio of chitin/chitosan, ranging from biomatrix to quantum dot.

2. Chitin/chitosan biopolymer: multitask portfolio from biomatrix to quantum dot

Chitin is the second most copious biomolecule after cellulose and is found in arthropod exoskeletons like crustaceans (crabs, lobsters and shrimps), radulae of the phylum Mollusca, cephalopod beaks, lissamphibian scales, tetrapods, fish, as well as in the framework of fungi cell walls [1, 2]. Chitin is like cellulose in structure but differs at the C2 hydroxyl position and substitutes poly-(1 → 4)-β-*N*-acetyl-D-glucosamine links to yield an *N*,*N*′-diacetylchitobiose helix where each sugar unit is mutually inverted with a neighbour via 180° rotation [2]. Such structural features of chitin impart high stability/rigidity due to skeletal interconnected hydrogen bonding. Ubiquitous chitin is accumulated as a structural constituent in organisms and is prevalent in the biosphere and fossilized matter like Pogonophora and insect wings found in Cambrian fossil: amber [3]. The multitask portfolio of chitin ranges from biomatrix/biosensor to quantum dot, all of which possess vital qualities, and include antioxidants, hydrogels, adsorbents, diagnostic testing/therapy, drug delivery, coating/process film, cosmetics, tissue templates, active pharmaceutical ingredients, biomedical scaffolds like wound dressings, contact lenses, microspheres, etc. [4]. Chitin's average molecular weight of 2×10^6 Da with 7% w/w-enriched nitrogen is a vital raw material for the medical, paper/pulp, food, textile, photography and environment industries [1–8]. Chitin has α, β and γ allomorphs self-assembled via legitimated crystallization as microfibrils, as shown in **Figure 1**. Natural chitin is the α form and has antiparallel *N*,*N*′-diacetylchitobiose units [1–3], while the β and γ forms are less vital and seldom observed in nature, e.g., mushrooms.

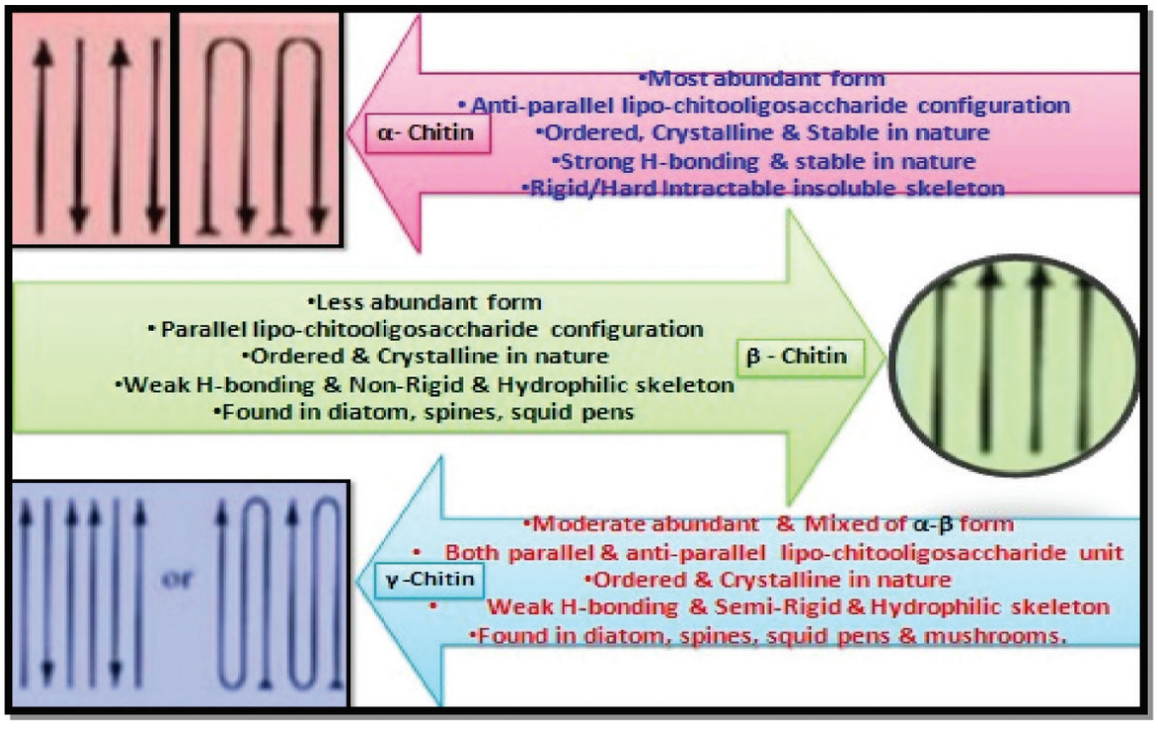

Figure 1. Self-assembled, legitimated, crystallized α, β and γ allomorphs of chitin.

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Chitosan is daecetylated chitin, and there numerous papers and patents that signify its utility in biology, genetics, physics, chemistry, polymers, tissue engineering and biomedicine. Assorted physicochemical alterations in flexible chitosan offer unique matrixes like blends, hybrids, films, sheets, dendrites, composites and gels pertaining to superior prospective, unparalleled competency in modern scientific growth [1–8]. Hence, chitin/chitosan biomatrixes have been explored and summarized in unequivocal portfolio applications in S&T.

Raw chitin/chitosan is hydrophobic in nature and has limited solubility in many organic solvents, so possesses a narrow utility. Yet, both chitin and chitosan own special innate features, e.g., they are hydrophobic, polycationic, less immunogenic, highly porous, haemostatic, non-toxic, biodegradable, biocompatible, bioadhesive, antibacterial and antimicrobial [8–10]. Chitosan holds proactive $–NH_2$/–OH groups as free and fragile for assorted chemical modifications, namely, C6 carboxylation, *N*-acylation/alkylation, *N*-quaternization, protonation to NH_3^+, which further improves its pH dependency (acid to alkaline), resultant solubility and utilities [10, 11]. The chitin/chitosan market was augmented to US$2900 million in 2017; furthermore, Global Industry Analysts Inc. expects to boost that figure to US$63 billion by 2024. However, the current global need for chitin is over 6000 tonnes, while all-inclusive production is at 28,000 tonnes [1, 2].

Chitosan has free NH_2/OH proactive groups, which on protonation aids metal chelation at neutral pH, whereas anionic complexation occurs due to coagulation and flocculation of contaminants at pH > pK_a [8, 10]. Such coagulation/flocculation imparts a stoichiometric charge restabilization of particulate suspensions along with patch destabilization and bridging with dissolved solutes, resulting in remediation of hazardous/toxic metal. Nanotechnology has

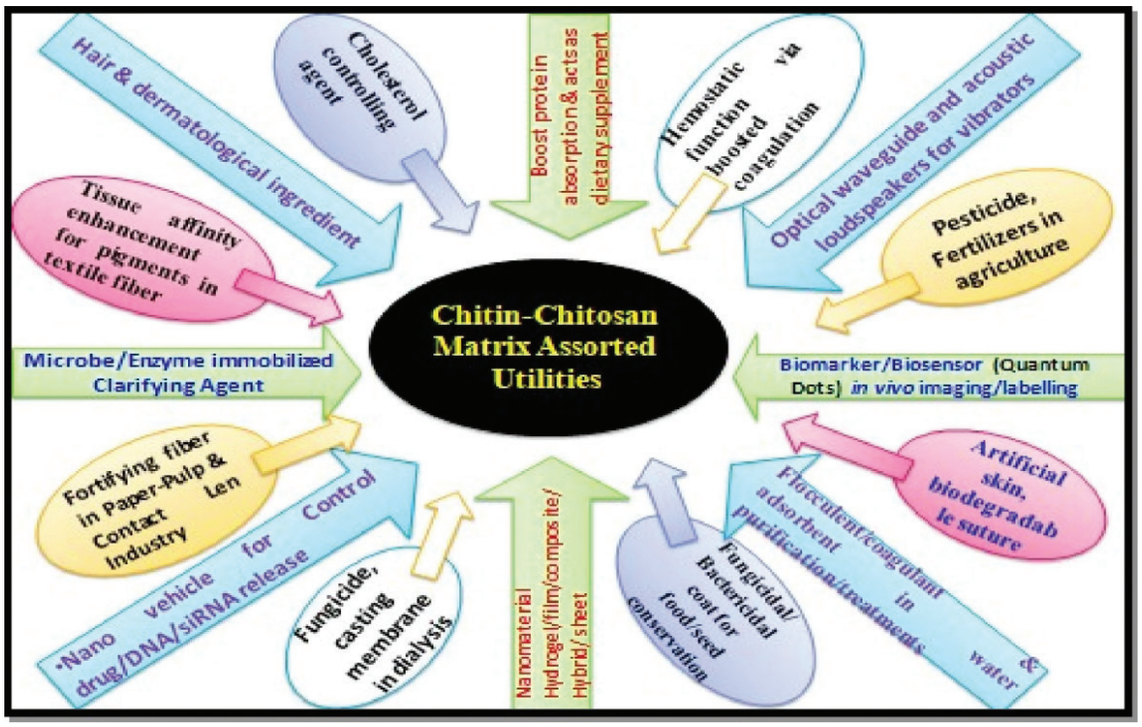

Figure 2. Assorted products and a wide range of uses of chitosan in modern science (incomplete list).

manipulated the chitosan skeleton to yield tubular templates/scaffolds that optimize regenerative relevance, including repair, replacement, maintenance and enhancement of injured cells/organs via tissue engineering [2, 10]. Such a tailored chitosan matrix has high porosity, suitable porosity/collapse aversion and unique structural integrity, which impart a multitasking portfolio ranging from biomarkers/biosensors to quantum dots [10]. Thus, chitosan chemistry offers myriad uses, namely, neo-tissue degradation/creation, cell differentiation, interactive adhesive proliferation and overall migration, as depicted in **Figure 2**.

3. Chemistry of chitin/chitosan

3.1. Biosynthesis of chitin

Several extremely complex biosynthesis steps resulting in a chitinous supramacromolecular skeleton in an arthropod cuticle and fungus cell wall are mentioned below:

- Trehalose/glucose sugar units undergo sequential biotransformation, including phosphorylation, amination and uridine diphosphate (UDP)-*N*-acetylglucosamine substrate formation.
- Enzyme chitin synthase yields a chain as part of protein/carbohydrate cluster counting via intimate topologic packing, which gives a budding chitin coalescence into crystalline fibrils.
- The chitin conformational orientated is continued till long chain polymer translocation across the plasma membrane occurs.
- Lastly, microfibril formations and crystallization are achieved via interchain hydrogen bonding, and an alliance with cuticular protein/carbohydrate yields toughness.

Chitosome enzymes in endoplasmic reticula, Golgi organelles and vesicles enclosed in zymogenic clusters that have cytoplasmic microvesicles at the hyphal tip play a crucial role in predetermined chitin trafficking [11]. Chitosome fused with a plasma membrane activates raw/crude chitosan (CS) units via a proteolytic reaction; further CS insertion engrosses intercession of targeted proteins. Chitosome in epidermal cell-free insects via UDP-*N*-acetyl-D-glucosamine: chitin4-β-*N*-acetylglucosaminyl-transferase; EC 2.4.1.16 *in vivo* yields chitin. In 1962, scientist Candy-Kilby had first proposed metabolic pathway as progressed with glucose and ended with UDP-GlcNAc unit observed in southern armyworm Spodoptera eridania (cell-free extracts), which aids to ascertain total chitin biosynthesis [7, 11, 12].

3.2. Origin and biofunctions

Chitin is a linear homopolysaccharide of *N*-acetylglucosamine, while chitosan is *N*-deacetylated chitin: both offer chemically stable *nitrogen* as a nutrient and an energy source for rumen microbe degradation, in addition to inducing molecular signals responsible for defensive stimulation in plants/animals. Lipo-chitooligosaccharide and chitin induce nitrogen fixation

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and regulate gene nodulation/Nod factor because of assorted bacteria via host–guest symbiosis in leguminous plants. Chitin also boosts the anionic exchange capacity of soil, lessens nutrients like nitrate and phosphate leaching, and recovers pesticide delivery and efficacy.

Crustacea possess chitins, proteins and calcium carbonate responsible for rigid exoskeleton creation, keeping the inner soft tissue safe from injury, offering defense against predators, avoiding dryness of delicate tissues and aiding survival. Chitin in protozoa, fungi cell walls, arthropods, nematodes and pathogenic organism skeletons offers defense against the exterior atmosphere [10].

3.3. Processing

Chitin yields via seafood processing from crabs, shrimps, shellfish, krill, clams, oysters and squid contain high protein, nitrogen and calcium carbonate, which are recovered via stepwise processing, as given in the schematic representation of **Figure 3**.

3.4. Formulation/grafting

The degree of deacetylation and drastic acid hydrolysis controls the cleavage of the β-D-glucosamine unit of chitin and yields assorted deacetylated chitosan. Chitosan on skeletal formulation reduces hydrogen bonding and under aqueous conditions forms swelled films in spite of hydrophobic alkyl links, thus dissolving in aqueous mineral acids yields polyelectrolytic matrixes like salts, films, hybrids, chelates/complexes and gels. Chitosan undergoes facile chemical adaptation such as esterification/etherification, hydrogenation, amidation, mono−/di−/tri-*N*-alkylation/acylation and aldimine/ketimine, Schiff-base formation in addition to sodium borohydride reduction to 1,3-melanin/1,6-β-D-glucan keto-amino acid. Certain formulated products of chitosan are immunostimulants that boost immunity in the host [2, 10].

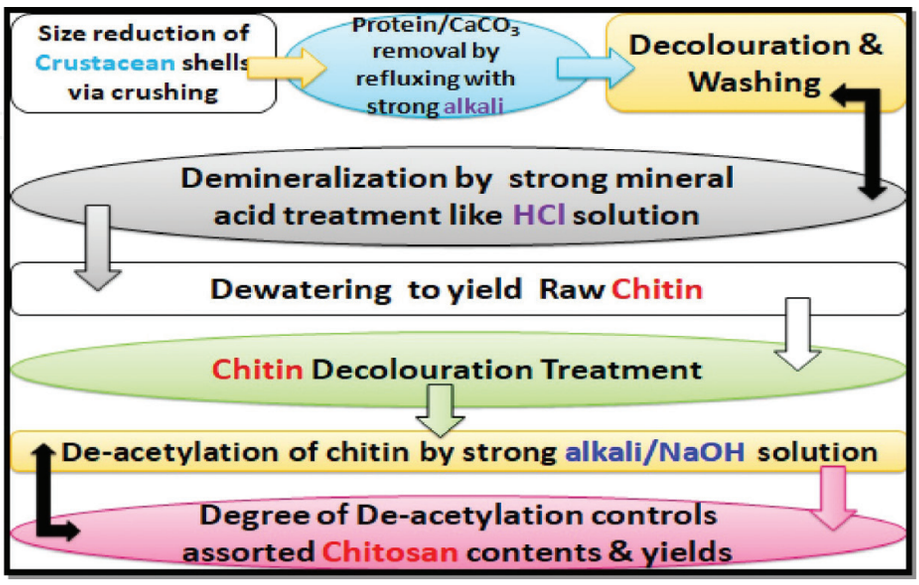

Figure 3. Schematic representation of crustacean processing to obtain chitin/chitosan.

3.5. Solubility

Chitin/chitosan contains a highly hydrophobic anhydroglucoside framework, which also has limited solubility in organic solvents. However, mixtures of organic solvents like hexafluoroisopropanol, hexafluoroacetone, chloroalcohol, 5% LiCl-dimethylacetamide and certain aqueous acetic acids, *N*-methyl morpholine-*N*-oxide and mineral acids were found to enhance the solubility of chitin/chitosan. Raw chitosan's solubility is affected by the degree of deacetylation and it absorbs moisture from the atmosphere. Chitin with 50% deacetylation is hydrophilic but a higher degree of deacetylation (>50%) is hydrophobic and immiscible in ordinary solvents, so it mostly reacts in the solid state [2].

3.6. Chemical and biological properties

Even if the β-(1 → 4)-anhydroglucosidic links of chitin are similar to cellulose, their innate nature is different. Chitin is a white, inelastic, inert, non-toxic, renewable, water-insoluble amino-polysaccharide that binds to the cell wall of phospholipids of Gram +ve bacteria and modifies cell permeability as well as inhibits certain enzymes. The high density (1.35–1.40 g/cm^3), slight basicity (pH >7) and moderate glass transition temperature (203°C) of chitosan aids selective fabrication of permeable membrane matrixes under acidic conditions. Being biocompatible with mammalian/microbial cells, chitosan assists connective gum tissue regeneration as well as accelerates osteoblasts better than other counterparts. Chitin is hemostatic, fungistatic, spermicidal, antimicrobial, antitumoral, anticholesteremic, and a CNS depressant and immunoadjuvant in nature, and is thus facile to binding mammalian/microbial cells [11]. Chitin/chitosan is a highly viscous and polyelectrolytic skeleton only soluble in aqueous solutions of some acids and lipids. Linear polyamine chitosan has proactive amino/hydroxyl functionality and is vulnerable to chemical modification/grafting. Body fluid lysozyme is facile and easily accumulated in chitin. It has myriad therapeutic uses, including fibroplasia-inhibited wound healing/dressing, absorbable stitches, and supports tissue/cell growth and differentiates cells. Chitosan sutures hasten and enhance certain clinical phenomena like wound healing and dressing texture, which are not easily attained in other counterparts. Chitosan scaffolds/templates chelate transition metals and exhibit enzyme immobilizations [2].

3.7. Derivatives

Derivative formation, phase transformation and significant polyfunctional alterations at NH_2, the primary/secondary OH group of chitosan, yields matrixes like composites, blends, gels, films and polyampholytes, as mentioned below [2–10].

3.7.1. N-Phthaloylated chitosan

Chitosan in phthalic anhydride-DMF solution undergoes *N*-phthaloylation, boosts solubility and fastens bulkiness due to its aversion to hydrogen bonding. Water discriminates against functional selective and quantitative *N*-phthaloylation and has a superior reactivity via tritylation/detritylation and the alcoholysis precursor for C6 substitution over *N*,*O*-phthaloylation/*O*-phthaloyl. It offers easy and suitable chemoselective protection for chitosan amino groups in scaffolds used in electrochemical devices.

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3.7.2. Sialic acid/chitosan dendron

The water philicity of chitosan is enhanced effectively via gallic acid as a branching part, and triethylene glycol as a spacer arm yields a dendronized form. Residual amines undergo *N*-succinylation and boost the water solubility of resultant dendrites as chitosan is conjugated to preformed dendrons viable for effective drug/gene delivery.

3.7.3. Thiocarbamoyl chitosan

Methyl/phenylthiocarbamoyl substitution obtained via thiocyanate/thiourea in a eutectic ammonium mixture grafted onto chitosan was found to selectively entrap assorted metal adsorption, e.g., $Au^{+3}/Au^{+1}/Au$ and Pt^{+5}/Pt^{+2} adsorption from contaminated water. This matrix showed augmented adsorption of metal ions onto the monodentate sulfide ligand coordination bond, and/or chelation often showed elevated affinity as per the Pearson principle.

3.7.4. Chitosan hydrogels

Hydrogels are polymeric systems that are found to be puffy in aqueous conditions, but retard water solubility due to cross-linked chains via one or more monomer interlockings. Such hydrophilic gels/hydrogels have polymeric chain networks as colloidal crystals dispersed in water medium. Hydrogels have been substantially noticed in past decades by virtue of their unique features like innate flexibility, normal tissue and bulk water content and outstanding guaranteed applications. Inherent hydrophobic, chitosan-based hydrogels are superior due to their longer durability, high water absorption, elevated gel strength and progressively substituted synthetic hydrogels. Chitosan has a well-defined skeleton ideal for the design of biodegradable and functionalized hydrogels that are stable in variable fluctuating conditions of temperature and pressure. Chitosan-derived hydrogels are more selective, cheap and environmentally friendly because of their high intrinsic sorption affinity and performance, which are elevated by physicochemical formulations intended for focused usage, namely, endotoxin separation of protein, lipid, lipopolysaccharide and chiral drugs. 3D chitosan, laminar, crossed-linked, two-/multicomponent hydrogels are developed in water to fill voids/spaces that vary with density and degree of acetylation of chitosan. Delivery of localized drugs/genes is achieved via slow release hydrogels, which consequently reduce off-targeted side effects of drugs. Chitosan hydrogels are straight grafted via D,L-lactic/glycolic acid treatment, impart huge interfacial water interactions as side chains and are cross-linked/aggregated to yield pH-sensitive sites. Chitosan hydrogels have impending clinical utilities, including wound dressing/healing and as cell and tissue carriers/arrays.

3.7.5. Chitosan microcapsule

The microcapsules are spherical empty particles of varying size from 50 nm to 2 mm. A surface-active chitosan base microcapsule is similar to a quantum dot, which conveys bulk and discrete electronic properties, namely, it holds the electron hole and has tuneable optical activity, long fluorescence and photostability, which are more beneficial than other fluorophores used in the recognition, tagging and imaging in biomedicals [1–5]. The laminar cationic $–NH_2$/–OH linkages of chitosan aid microcapsule creation via anionic knits with quite stable hybrids

[6], e.g., chitosan/sodium alginate and CS/nano-ZnS microcapsules offer efficient bioimaging/labelling as well as controlled drug/gene delivery. Rationally homogenized microcapsules of chitosan can be obtained by coacervation, emulsification, solvent evaporation and gas–liquid, microfluidic and layer-by-layer assembly techniques [7]. Chitosan microcapsules can entrap surfactants like CdS, ZnS cyclodextrin and sodium dodecyl sulfate to yield host–guest interactive external stimuli-sensitive hydrophobic cavities employed for the detection of toxic/hazardous contaminants. Surfactants induce certain skeletal changes that slightly control the shape and size in corresponding monodisperse microcapsules for the detection of pollutants.

Proactive amines in acidic conditions induce protonation and aid efficient $Ca(OH)_2$ coating onto chitosan to achieve pH-trigger microcapsules that impart an enduring antibacterial profile against *Enterococcus faecalis* microbial refractory strains in endodontic treatment and controlled drug delivery. A chitosan microcapsule that recuperates with native $Ca(OH)_2$ is practicable for osteogenesis and is viable for low inflammatory responses such as in bone defect healing as it evades bone resorption.

3.7.6. Biosensor/biomarker

Sensors respond and convert signals into magnetic/electrical fields that are easy to detect by other devices. Advanced biotechnology has prepared many biosensors to coalesce through chitosan to be used for the detection of diverse species, namely, tissues, cells, microorganisms, organelles, enzymes, antibodies, enzymes and nucleic acid [9]. Chitosan biosensors are preferred due to their uniqueness; they are cheap, biocompatible, ecofriendly, flexible, portable, more sensitive, naturally selective and respond more rapidly than other counterparts [2–10]. Certain nanocarbon-doped chitosan amperometric biosensors have huge surface areas, electrical conductivity and easy diffusion and are effective for enzyme immobilization, glucose estimation and the creation of fuel cell bioelectrochemical devices [13, 14].

A biomarker indicator shows the measurement/valediction of biostate, organism survival, pathogenic process and therapeutic prime response, and supervises cancer stages, clinical screening prior to diagnosis, risk assessment and disease detection as well as staging, grading and initial treatment in auxiliary therapy [15, 16]. Gold-coated chitosan/xanthan and graphene nanosphere-derived biomarkers are used for bioimaging, analysis in signal-improved melanoma cancer diagnoses, α-fetoprotein detection and carcinoembryonic antigen discovery, and are more accurate than electrochemical sensors and the ELISA test [17, 18]. Chitosan biomarkers are preferred for their due-advantage services in disease prevention, drug/tissue/cell delivery, dentistry, orthopaedics, ophthalmology, surgery and as an optical-wave guide, as shown in **Figure 4**.

3.7.7. Chitosan-based quantum dot

A quantum dot is 'nanometric/zero-dimensional particle' pertaining to semiconductor, optical-electronic quality, tuned via the size, shape and arrangements of dots/particles of used material. Nanotechnology aids in the encapsulation of quantum dots in the chitosan skeleton, which show remarkable high thermal/mechanical stability, better water solubility exploited for tumor-targeted delivery, anticancer therapy and designed drug release/loading [2–11, 13–17, 19]. Chitosan's amino-functionalized carbon quantum dots (CDs) possessed enviable

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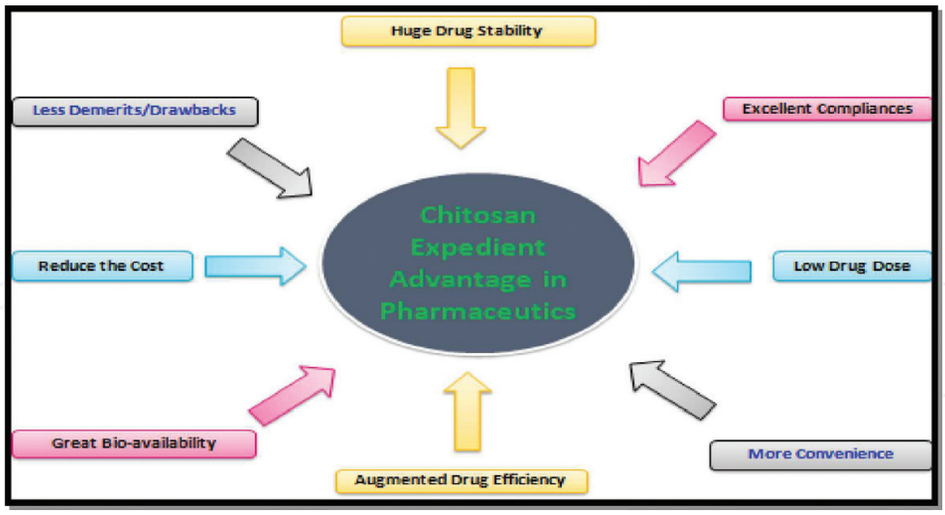

Figure 4. Chitosan expedient advantages in pharmaceutics.

surface proactive amino functionality which can exhibit bright luminescence with high quantum yield of 5% with up-conversion fluorescence effects. Such CDs possess robust UV rays obstacle detection as vital for autonomous navigations in solar devices/cells. Besides, exhibited elevated features than other commercial materials viz; low cytotoxicity, great hydrophilicity, biocompatible and well photo-stable which jointly tenders fluorescent biosensing desired in cancer diagnosis therepy along with cellular imaging and effective drug delivery [2–4]. Nano-ZnO-coated chitosan/glucose-encapsulated carbon quantum dots are designed for layer-by-layer sensitized nanosolar cells. Chitosan-doped cysteine/cadmium/tellurium quantum dots are favoured over counter-immune sensors for their antibacterial profile, electrochemical/luminescent offender DNA biosensing in chronic myelogenous leukemia, antibody immobility and specific protein detection [2–11, 13–17, 19]. Chitosan-formatted quantum dots are quick to generate safe/effectual delivery, silence unwanted gene expression/defects in curing diseases and can deliver genetic plasmids, DNA, si-RNA and oligonucleotides [13–20]. Nanometal-homogenized chitosan quantum dots offer controlled catalytic activity for multiple site selective gaseous adsorption/desorption [20, 21]. Platinum-entrapped polyacrylonitrile/chitosan quantum dots are deposited onto pencil graphite electrodes to be used in synergic water electrolysis and are excellent for facilitated hydrogen evolution reactions and skilful hydrogen production [21]. Chitosan-stabilized hyperbranched ligand quantum dots are multiresponsive drug delivery agents, luminous bioimaging sensors and semiconductors.

3.7.8. Chitosan nanoparticles

Selective and automatic morphological controls for shape/size-distributed chitosan-based nanoparticles are formulated via surface chemistry modifications. Laminar chitosan avoids nanoparticle aggregation and reduces involuntary stress via lyophilize-freezing and spray-drying techniques, but desired/safe characteristics can be formulated by pure ionotropic gelation (onto low-molecular chitosan). Chitosan/gadopentetic acid nanoparticles obtained via gadolinium neutran capture are thermally stable, robust and integrated, and thus helpful for molecular signalling, exogenous gene/drug delivery and intratumoral cancer therapy. Chitosan-doped nanoparticles augment self-branching in the resultant matrix, e.g., *N*,*N*,*N*-trimethylated

chitosan scaffolds impart extracellular competent intracellular drug release and compel better DNA transfer, superior cellular uptake and fine gene silencing [1–8]. The chitosan-blended nanopolyglycolide template has vital utility by entrapping doxorubicin drug, adorning dose-dependent non-viral devices for pulmonary si-RNA delivery, controlling H1299 gene silencing and exhibiting fluorescent protein cell expression [8–11, 13–20]. Nanotechnology aids the fabrication of advanced 2D/3D chitosan nanoscaffolds, namely sponges, foams, gels and fibres/films, for significant and precise encapsulation of nutrient/drug/tissue, which does not affect healthy cells, and is preferred in cancer chemoprevention procedures [1–11, 13–20].

3.7.9. Cosmetic uses

Biopolymer chitosan-derived hydrocolloid systems are solely cationic in its physicochemical character and gets viscous on aqueous acid neutralization, thus can prefer to intervene skin covers and artificial hairs over commercial polyanionic colloids. Chitosan is inherently fungicidal and fungistatic hence, preferred as raw/feedstock for preparation of assorted marketable beauty and cosmetic products [19]. A chitosan/alginate microcapsule has been developed to embody many species like hydrophobics, dyes and harmful UV absorbing agents. Sonat Company, USA, inserted antioxidant, antiallergic and antiinflammatory agents in chitosan to develop novel depilatory compositions to be used in cosmetics for curling hair and for skin and oral care. Biomaterial human hair composed of α-keratin owing few disulfide/$^{-}$S−S^{-} anionic linkages, and chitosan being polycationic thus utilize in synthetically developed formulations viz; elastic foams/emulsions employed in in many shampoo/conditioning products for synchronize boosting, soften/smoothen and strengthen of hairs. Chitosan-formulated hydrogels are employed in shampoos, rinses, styling lotions, hairsprays/colorants and permanent wave agents in hair-care products. Diacid anhydride-treated chitosan imparts a cationic charge and its high molecular weight stops skin infiltration, therefore it can compete with hyaluronic acid in skin-care products/cosmetics such as moisturizers, pastes, mouthwashes, chewing gums, packs, lotions, foundations, eye shadows, lipsticks, cleansing/bathing agents and nail enamels/lacquers. Chitosan mask silicon oxide salts are supplemented in toothpaste as a powder binder to uphold its granular shape. Chitin-based dental fillers are developed to stop candida/thican sticking to teeth and for cleaning false teeth [2, 10].

3.7.10. Chitosan in science and technology

The annual synthetic plastic consumption rate is 300 million tonnes; moreover, artificial polymers are merely 3% recyclable and 97% of plastic waste accumulates in the seas and oceans or in landfills, which harms our planet. Nevertheless, natural polysaccharide chitosan-based bioplastics are more biocompatible and biodegradable, and have equal utility with synthetic plastics. Encouraged by chitin, Boston researchers at the Wyss Institute for Biologically Inspired Engineering, USA, developed a silk protein and chitin-based, biodegradable, cheap, versatile, reinforced and tough plastic alternative called 'Shrilk' [10]. It is claimed that Shrilk would replace plastic in all consumer products, including suture wounds and scaffolds in tissue/cell revival. Shrilk composite consists of laminar plywood-like layers altered via

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mechanical and chemical interactions of chitosan/fibroin laminates. Shrilk is composed of fibroin protein derived from silk and chitin, usually extracted from discarded shrimp shells. Shrilk has strength and toughness similar to aluminium alloy, but it is only half the weight and can easily stretch from elastic to rigid complex shapes/sizes such as tubes, sheets, films, rubbish bags, packaging, nappies, etc. Shrilk is cheap, environmentally friendly, remarkably hard, biocompatible and bears high loads, thus it is employed in suture wounds in hernia repair and is a versatile template for tissue regeneration. Shrilk offers potential environmental solutions and is emerging as a stepping-stone toward noteworthy therapeutic advancements like Food and Drug Administration-approved implantable medical devices, bone-tissue gallows, laminar silk fibroin, biocomposts/fertilizers to release N/P nutrients, surgical closure scaffolds and wound healing. Nanotechnology has altered chitosan's characteristics, including biological, physico/electrochemical cellular response and molecular motions, which aid in yielding biodegradable, biocompatible, non-toxic, antimicrobial and immunogenic matrixes for sustainable intracellular drug/protein delivery, cell array and the uptake of hydrophilic agents across epithelial layers [1–10].

4. Limitation and remedy

Apart from its vast uses, chitosan has a few disadvantages, e.g., a weak base (pK_a 6.2), little affinity for acids, low mechanical strength and it is immiscible in aqueous and many organic solvents [11]. Moreover, chitosan-based materials exhibit major puffiness in water and cause unusually fast drug delivery; hence, its parent skeleton seeks assorted physicochemical alterations. Some limitations of raw chitosan can be conquered via proactive amine/hydroxyl formulations to achieve the desired applicability.

5. Futuristic applications of the chitin/chitosan matrix

Nanotechnology has helped to design rational chitin/chitosan biocomposites with myriad applications in modern S&T [2, 14, 21]. Chitosan-integrated membranes in contrast to traditional membranes assist in the retention and remediation of toxic/hazardous contaminants [2]. Also, chitosan-based material imparts unique features, namely, progressive working efficiency, great adsorption profile for desalination and water/wastewater treatment processes, along with compliant large-scale utility for point-of-use devices [13–21]. Chitosan products like nanofilms/sheets, hydrogels, microcapsules, proliferated high-resolution devices, templates, scaffolds and quantum dots are derived via tailoring structural and chemical functionality with a view to having an unequivocal multitasking portfolio in modern scientific achievements [19], in addition to tackling the global challenges in the mitigation of environmental pollution [14, 18]. Chitosan-based products boost many water purification/desalination systems, show no interfacial limitations and also improve work efficiency in the field of S&T, as depicted in **Table 1**.

Utility	Nature of work	Features
Energy	Sunlight conversion (e.g., Dye sensitized solar cell (DSSCs), and power conversion efficiency (PCE))	Proficient light harvesting, especially in biomaterials/ biocomposites; fast charge separation; more current density; improved gas permeability; high storage density; rapid electron/ion transport; less resistance
Life sciences	Engineered/designed biomaterials, films, sheets, hydrogels, composites, etc.	Biocompatible; biodegradable; supports cell adhesion; controls dimension (shape/size and porosity); good mechanical/thermal stability
Chemical sciences	Preconcentration devices, bioreactors, emulsion/oil-H_2O separation, gas adsorption	More permeable; homogeneous flow via designed porosity; controllable dimensions and surface properties; monolithic column
S&T	Shrilk: biodegradable plastic	Entirely degradable bioplastic derived from shrimp and silk protein as a substitute for synthetic plastic, implantable medical devices
	HemCon® PRO Chitosan Technology: biomaterial product	Material produced and branded by Tricol Biomedical HemCon® having exceptional haemostatic, antibacterial features by virtue of strong polycationic charge onto chitosan-altered matrix and harvested in pristine waters of the North Atlantic. Haemostaticity imparts fast adherence/sealing to injured tissues/cells and promotes clotting. Verifies controlled bleeding in anticoagulated patients, arterial wounds with better efficiency than minerals, cellulose.

Table 1. Chitosan-based product applications in the field of S&T [1–11, 13–21].

6. Summary

Chitosan biopolymer is preferred for pharmacological and industrial purposes due to its innate features, namely, high mucoadhesion, biocompatibility, biodegradability, cheapness, non-toxicity and environmentally benign matrix. Advanced science has accomplished chitosan modality to offer assorted formulations like nanovehicles for cell/gene/DNA/RNA release, quantum dot use for never-ending scientific utility, namely, disease detection/ diagnosis, engendering new therapeutic techniques and tissue engineering for both life and Mother Nature.

The scientific facts, findings and fundamental aspects of chitosan chemistry imparts vital commercial applications which fascinated basic and applied research, resulted numerous papers, books and patents in chitin/chitosan sciences every year and this chapter/book is one of such endeavor. Thus, key challenges are highlighted as being compiled with current informative data to understand and create the enormous interest in the chemistry and science of chitosan. Chitin, like many polysaccharides, does not display requisite characteristics crucial for desired applications and thus it is mandatory to perform certain skeleton cationic, anionic, amphiphilic and crosslink formulations at free/proactive amino/hydroxyl functionalities as discussed. All such rationally tailored modifications endow the desired applicability to encompass the wide fields of biomedical/clinical research, pharmaceutics, cosmetics, foods, paper/pulp, textiles, agriculture, water treatment and permeation. This book will contribute to the literature on chitin/chitosan principally on the progress

demonstrated with novel scaffolds, templates and matrixes, which have myriad utilities. The book will inspire researchers to carry on discreet efforts so that chitosan can occupy its worthy status within the field of biopolymers.

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