

An Overview of Natural Polysaccharides as Biological Macromolecules: Their Chemical Modifications and Pharmaceutical Applications

Harshal Ashok Pawar*, Swati Ramesh Kamat and Pritam Dinesh Choudhary

Dr. L. H. Hiranandani College of Pharmacy, Ulhasnagar-421003, Maharashtra, India

Abstract

Any pharmaceutical formulation contains two ingredients one is the active ingredient and other is an excipients. An excipient helps in the manufacturing of dosage form and it also improves physicochemical parameters of the dosage form. Polymers play an important role as excipients in pharmaceutical dosage form. They influence drug release and should be compatible, non-toxic, stable, economic etc. Biopolymers, synthetic polymers and their derivatives are commonly used in medicine and pharmacy. They are broadly classified as natural polymers and synthetic polymers. Nowadays, due to many problems associated with drug release and side effects manufacturers are inclined towards using natural polymers and their derivatives. Natural polymers are basically polysaccharides so they are biocompatible and without any side effects. This review article aims at discussing various sources, pharmaceutical applications and the different techniques used for modification of natural polymers.

Keywords: Natural polymer; Polysaccharides; Grafting**Introduction**

A polymer is macromolecules composed of repeating structural units which are connected by covalent chemical bonds (Figure 1). The term "polymer" is derived from the ancient Greek word *polus* which means "many or much" and *meros*, meaning "parts". It refers to a molecule whose structure is composed of multiple repeating units, having a characteristic of high relative molecular mass and attendant properties. The units composing polymers derive from low relative molecular mass molecule. The term was coined in 1833 by Jöns Jacob Berzelius, though with a definition distinct from the modern IUPAC definition [1]

Polysaccharides are a diverse class of polymeric materials of natural (animal, plant, algal) origin formed via glycosidic linkages of monosaccharides [2]. Depending upon the nature of the monosaccharide unit, polysaccharides are classified as linear or branched chain polysaccharides. Polysaccharides possess a number of reactive functional groups in their chemical structure, including hydroxyl, amino, and carboxylic acid groups, indicating the possibility for chemical modification [3]. Molecular weight of naturally occurring polysaccharide varies between hundreds to thousands of Daltons, further increasing diversity [4].

Although synthetic and natural polymers are available, the use of

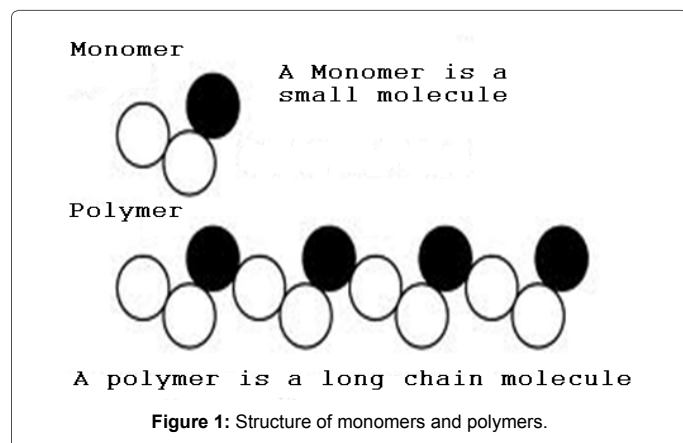
natural polymers for pharmaceutical applications is attractive because they are economical, readily available and non-toxic. They are capable of chemical modifications, potentially biodegradable and with few exceptions, also biocompatible [5]. Substances of plant origin pose several disadvantages like being synthesized in small quantities and in mixtures that are structurally complex, which may differ according to the location of the plants as well as other variables such as the season. This may result in a slow and expensive isolation and purification process. Also there is another issue which is become increasingly important is that of intellectual property rights [6,7]. The plant-derived polymers not only have applications in pharmaceutical formulations like their use in the manufacture of solid monolithic matrix systems, implants, films, beads, microparticles, nanoparticles, inhalable and injectable systems but also in viscous liquid formulations [8-10]. In these dosage forms, polymeric materials play different roles such as binders, matrix formers or drug release modifiers, film coating formers, thickeners or viscosity enhancers, stabilizers, disintegrants, solubilisers, emulsifiers, suspending agents, gelling agents and bioadhesives [11].

Different Sources, Chemical Composition and Applications of Natural Polysaccharides

Table 1-6 provides the information regarding source, chemical constituents and application of different natural polysaccharides.

Modification of Natural Polymers

The intrinsic structure and properties of nonionic, anionic, and cationic gums make them found extensive application in various



*Corresponding author: Harshal Ashok Pawar, Assistant Professor and Head of Department (Quality Assurance), Dr. L. H. Hiranandani College of Pharmacy, Smt. CHM Campus, Opp. Ulhasnagar Railway Station, Ulhasnagar-421003, Maharashtra, India; Tel: +91-8097148638; E-mail: harshal.dlhcop@gmail.com

Received December 15, 2014; Accepted December 31, 2014; Published January 08, 2015

Citation: Pawar HA, Kamat SR, Choudhary PD (2015) An Overview of Natural Polysaccharides as Biological Macromolecules: Their Chemical Modifications and Pharmaceutical Applications. Biol Med (Aligarh) 6: 224. doi: [10.4172/0974-8369.1000224](https://doi.org/10.4172/0974-8369.1000224)

Copyright: © 2015 Pawar HA, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Common name	Botanical name	Chemical constituents	Application	References
Okra (<i>Lady's finger, Gumbo, Bhindi</i>)	<i>Abelmoschus esculentus</i> (Malvaceae)	Galactose, galacturonic acid, and rhamnose and with some fractions of glucose, mannose, arabinose and xylose	Suspending agent, disintegrating agent	[12-14]
Phoenix mucilage (Date palm, <i>Pindakharjura, Khajur</i>)	<i>Phoenix dactylifera</i> (Palmaeaceae)	Fructose, sucrose, mannose, glucose and maltose in addition to small amounts of polysaccharides such as pectin (0.5 - 3.9%), starch and cellulose	Binder	[15]
Cordia Mucilage (Bhokar, Semar, Vidi)	<i>Cordia Obliqua</i> (Boraginaceae)	Arabinose, galactose, pyrralinoses	Expectorant, gonorrhoea treatment, tablet binder, emulsifier	[16]
Jackfruit (Ceylon jack)	<i>Artocarpus heterophyllus</i> (Moraceae)	Galactomannans, starch	Suspending agent, emulsifying agent, Binder, mucoadhesive, release retardant	[17,18]

Table 1: Source, chemical constituents and application of polysaccharides obtained from fruits.

Common name	Botanical name	Chemical constituents	Applications	References
Tamarind seed polysaccharide (<i>Imli, Chinch</i>)	<i>Tamarindus indica</i> (Fabaceae)	Glucosyl : xylosyl : galactosyl in the ratio of 3:2:1	Formulation of matrix tablets, biodegradable carrier for colon specific drug delivery, novel bioadhesive	[19,20]
Fenugreek mucilage (Methi)	<i>Trigonella foenum-graceum</i> (Leguminosae)	Galactomannans	Matrix formulation, release retardant.	[21]
Locust Bean Gum (carob gum)	<i>Ceretonia Siliqua</i> (Leguminosae)	D-galacto-D-mannoglycan, cellulose, pentan, galactomannan.	Superdisintegrant, in controlled delivery system, in colonic drug delivery.	[22-24]
Tara gum (Taya, Spiny hold back)	<i>Caesalpinia spinosa</i> (Leguminosae or Fabaceae)	Mannose : galactose in ratio 3:1	Thickening agent, stabilizer, in formulation of gastroretentive controlled release tablets	[25]
Honey locust gum (Thorny Locust)	<i>Gleditsia triacanthos</i> (Leguminosae)	galactomannan	In formulation of matrix tablets.	[26]
Cassia Tora mucilage (<i>Tarota, Takla, Cassia semen</i>)	<i>Cassia tora</i> (Caesalpinaceae)	Arabinose and glucose	Binding, suspending agent.	[27,28]
Mimosa scrabella	<i>Mimosa scabrella</i> (Mimosaceae)	Galactomannan -mannose: galactose ratio of 1.1:1.	Release-controlling agent	[29]
<i>Mimosa pudica</i> (Touch-me-not, <i>Chui-mui, Lajalu</i>)	<i>Mimosa pudica</i> (Mimosaceae)	d-Xylose and d-glucuronic acid.	Swelling agent, in formulation of controlled delivery system	[30]
<i>Ocimum mucilage</i> (<i>Sweet basil, Ram Tulsi, Sabje, Sabza</i>)	<i>Ocimum americanum</i> (Lamiaceae)	Xylose, arabinose, rhamnose and galacturonic acids	Tablet disintegrant	[31,32]
Black gram (<i>urad dal</i>)	<i>Vigna mungo</i> (Fabaceae)	Protein, fat, fibre, minerals, carbohydrates	Suspending agent, matrix forming agent for sustained release tablet.	[33,34]
<i>Gulmohar mucilage</i> (<i>goldmohar</i>)	<i>Delonix regia</i> (Fabaceae)	Glucomannose	Tablet binder	[35]

Table 2: Source, chemical constituents and application of polysaccharides obtained from seeds.

Common name	Botanical name	Chemical constituents	Applications	References
<i>Albizia gum</i> (<i>Albizia Brownie, Inga zygia</i>)	<i>Albizia zygia</i> (Leguminosae)	Galactose	Emulsifier, tablet coating.	[36,37]
Almond gum (Almond, <i>badam</i>)	<i>Prunus amygdalus</i> (Rosaceae)	Aldobionic acid, L-arabinose, L-galactose, D-mannose	Emulsifier, suspending agent, glazing agent, stabilizer, thickner, binder	[38]
Cashew gum (cashew, <i>kaju</i>)	<i>Anacardium occidentale</i> (Anacardiaceae)	Galctose, arabinose, rhamnose, glucose, glucuronic acid	Gelling agent, binder, used in formulation of controlled delivery system	[39-41]
Moringa oleifera gum (Moringa, drumstick tree, benzoil tree)	<i>Moringa oleifera</i> (Moringaceae)	arabinose, galactose and glucoronic acid	Gelling agent, binder, release retardant, disintegrant	[42-44]
Gum damar (Black Dammar, Indian white mahogany, <i>Daamar</i>)	<i>Shorea wiesneri</i> (Dipterocarpaceae)	Beta and alpha resins, dammarol acid	Binder, sustained release matrix, microencapsulating agent	[45,46]
Gum Copal (Indian copal tree, Malabar tallow tree, <i>Chandrusa</i>)	<i>Bursera bipinnata</i> (Burseraceae)	Agathic acid, cis-communic acid, trans-communic acid, polycommunic acid, sandaracopimaric acid, agathalic acid, monomethyl ester of agathalic acid, agatholic acid and acetoxy agatholic acid	Swelling agent, release retardant, film forming agent, carrier for colon specific drug delivery	[45,47,48]
Kondagogu Gum (<i>Bombax gossypium, Maximiliana gossypium, Galgal, Ganeri, Kondagogu</i>)	<i>Cochlospermum religiosum</i> (Bixaceae)	Rhamnose, galacturonic acid, glucuronic acid, D-glucose, galactose, arabinose, mannose and fructose	In formulation of Gastric floating drug delivery system, emulsifier	[49-51]
Bhara gum (<i>Vibhitaka, Aksha, Belleric myrobalan</i>)	<i>Terminalia bellerica</i> (Combretaceae)	β - sitosterol, gallic acid, ellagic acid, ethyl gallate, galloyl glucose and chebulaginic acid	Release retardant	[52]
Hakea gum	<i>Hakea gibbosa</i> (Proteaceae)	L-arabinose and D-galactose, glucuronic acid, mannose, xylose	Mucoadhesive, release retardant, bioadhesive polymer	[53,54]
Grewia gum	<i>Grewia mollis</i> (Tiliaceae)	Glucose, rhamnose	Binder, film forming agent, release retardant	[55-58]
Olibanum gum (Indian frankincense, <i>Shallaki, Dhupali</i>)	<i>Boswellia serrate</i> (Burseraceae)	Resin acids, polysaccharides, boswellic acid	Matrix forming agent, binder, microencapsulating agent	[59-61]
Terminalia gum	<i>Terminalia randii</i> (Combretaceae)	β - sitosterol, gallic acid, ellagic acid, ethyl gallate, galloyl glucose and chebulaginic acid	Binder	[62]

Table 3: Source, chemical constituents and application of polysaccharides obtained from Exudates.

Common name	Botanical name	Chemical constituents	Applications	References
Cocculus mucilage (moonseed)	<i>Cocculus hirsutus</i> (Menispermaceae)	Polysaccharides and a gelatinous material	Pharmaceutically used as binding agent, gelling agent	[63]
Aloe mucilage (Aloe, Gheekumari, Korpad)	<i>Aloe barbadensis</i> (Liliaceae)	Contains 1, 8 dihydroxy anthraquinone derivatives and their glycosides, Acemannan, arabinan, arabinorhamnogalactan, galactan, galactogalacturan, glucogalactomannan, galactoglucoarabinomannan and glucuronic acid.	Formulation of controlled delivery system.	[64,65]
Hibiscus mucilage (shoe-flower plant, China rose, and Chinese hibiscus)	<i>Hibiscus rosa-sinensis</i> (Malvaceae)	L-rhamnose, D-galactose, Dgalactouronic acid, and D- glucuronic acid	Sustained release matrix	[66,67]

Table 4: Source, chemical constituents and application of polysaccharides obtained from Leaves.

Common name	Botanical name	Chemical constituents	Applications	References
Polysaccharides obtained from whole plants				
Neem gum (Neem, Cherish)	<i>Azadirachta indica</i> (Meliaceae)	Mannose, glucosamine, arabinose, galactose, fucose, xylose and glucose	Binder, release retardant	[68,69]
Moi gum (Wodier, Jingini, Jhingan)	<i>Lannea coromandelica</i> (Anacardiaceae)	Roots contain cluytlyl ferulate; heartwood gives lanosterol; bark, dlepicatechin and (+) leucocyanidin; flowers and leaves, ellagic acid, quercetin and quercetin-3 arabinoside. Flowers also contain iso-quercetin and morin. Leaves in addition contain beta sitosterol, leucocyanidin and leucodelphinidin	Microencapsulating agent, release retardant	[70]
Polysaccharides obtained from microbial source.				
Curdlan	<i>Agrobacterium</i> spp. (Rhizobiaceae)	Glucose	Food additive (for example, as a thickener or a gelling agent), as controlled delivery system.	[71]
Gellan	<i>Sphingomonas</i> spp. (Sphingomonadaceae)	Glucose, rhamnose and glucuronate	Culture media additive, food additive (for example, as a gelling agent) or for encapsulation	[71]
Colanic acid	<i>Escherichia coli</i> (Enterobacteriaceae)	Fucose, glucose, glucuronate and galactose	Viscosity enhancer	[71]
K30 antigen	<i>Escherichia coli</i> (Enterobacteriaceae)	Mannose, galactose and glucuronate	Viscosity enhancer, controlled drug releasing agent.	[71]

Table 5: Source, chemical constituents and application of polysaccharides obtained from Whole plant and microbial source.

Common name	Botanical name	Chemical constituents	Applications	References
Konjac glucomannan (Devil's tongue, voodoo lily, snake palm, or elephant yam)	<i>Amorphophallus konjac</i> (Araceae)	D-Glucose and D-mannose	Controlled release matrix, gelling agent,	[72,73]
Taro (arvi)	<i>Colocasia Esculenta</i> (Araceae)	Galactose and arabinose	Binder, mucoadhesive polymer, matrix forming agent.	[74]

Table 6: Source, chemical constituents and application of polysaccharides obtained from Tubers.

areas, but the raw gum also emerges some drawbacks and cannot meet all application requirements for some special purpose. Thus, the modification of gums with acrive small molecules was conducted because the derivatives can not only bring the favorable properties due to the introduction of functional groups, but also keep the intrinsic advantages of gums to the greatest degree [75] and so the chemical modification always plays a dominant role to improve gums and open prospects for extending the application of raw gums. Generally, the chemical functionalization of gums mainly includes the esterification, etherification, and cross-linking reactions of hydroxyl groups.

Purpose of modification

To target at a particular site: 5-amino salicylic acid drug used for ulcerative colitis was formulated using cross linked chitosan. It showed disintegration in intestine and absorption occurred in small intestine which wasn't seen in the formulation with chitosan [76].

To make the polymers more heat or moisture resistant: Cellulose acetate is more heat resistant than cellulose. Studies have been performed on modifications of polymers and it was found to decrease degradation rate of the polymer thus making it heat and moisture resistant [77]

To alter its solubility, more sustainable: Derivatisation of

chitosan showed increased solubility in water as well as other organic solvents. Enzymatic method using hemicellulose enzyme was used to hydrolyse chitosan and reduce its molecular weight thus increasing its solubility [78]

To make it more flexible, more transparent, and more compatible and/or biodegradable: Kappa carrageenan has been subjected to play an important role as free radical scavengers in vitro and antioxidants for prevention of oxidative damage in living organisms. Although k-carrageenan has wide application range, it suffers from certain drawback like biodegradability, which limits its use considerably [79].

Biopolymers may also have unique characteristics such as antimicrobial effects, which can be used to add value to end products: Chitosan has antimicrobial activity and it has been tried to develop by derivatisation [80].

To reduce the toxicity: Guar gum blocks your gastrointestinal track contributing to blockage of absorption of other critical substances. For example, large amounts of guar gum may prevent metformin, an antidiabetic drug, from being absorbed in the intestines. In diabetic patient where it is necessary to have stable concentration of metformin, severe fluctuation can be seen because of guar gum. This can be reduced by use of its derivative [81].

Structural elucidation: The degree of substitution of cellulose and its derivative can be recognized by use of NMR technique [82,83].

Derivatives of Natural Gums

Carboxyl derivatives

It includes the addition of carboxyl or $-\text{COONa}$ group on the substrate. It uses different reagent to increase the hydratability and solubility of gum. The carboxymethyl derivative of cashew gum has negative charges, and can form physical complex with the cationic polymer such as chitosan.

Hydroxyethyl derivatives

The hydroxyethyl derivatives of gum can be prepared from natural gum via an irreversible nucleophilic substitution. The derivatives show better colloid properties than the raw gums, better solubility and thermal stability in solution, good dispersibility in water, and high compatibility with anionic, cationic, and nonionic surfactants.

Vinyl-functionalized derivatives

Many gums show poor reactivity and hence require addition of vinyl group so as to increase the reactivity for grafting purpose. Glycidyl methacrylate (GMA), acrylic acid, acryloyl chloride, and maleic anhydride are most commonly used modifying agents. Thus far, the vinyl-functionalized Arabic gum, guar gum, cashew gum [75], xanthan gum [76], and pectin [77] were prepared under basic condition.

Cationic derivatives

The cationic derivatives of gum have positive charges due to the introduction of cationic functional groups such as amino, ammonium, imino, sulfonium, or quaternary phosphonium groups [78,79].

Amphoteric derivatives

Amphoteric natural polymer contains both anionic and cationic substituents on its structure, which exhibits distinct properties in contrast to the individual anionic or cationic polymer and receives extensive applications in fine chemicals, papermaking, dyeing, and package materials [80-82]. The common methods to prepare amphoteric derivatives of gum include the following: (1) simultaneously modifying gum with anionic and cationic modifier [83] and (2) modifying gum with an amphoteric modifier [84].

Hydrophobic derivatives

The natural gums are mainly hydrophilic and soluble in aqueous medium, but it cannot meet the requirements for the application in organic solvent system. Other polysaccharide (i.e., starch, cellulose, chitosan) may form hydrophobic derivatives by introducing short chain hydrocarbon substituents through etherification reaction and show solubility in organic solvents [85].

Techniques of Derivatisation

“Physiosorption”, “grafting,” and “crosslinking” are the techniques used for the process of derivatisation of a polymer. The term physiosorption is related to physical attractive forces which is a reversible and is achieved by the end functionalized polymers on to the solid surface or self - assembly of polymeric surfactants. The term “grafting” can be described as the covalent attachment process and irreversible. Grafting can be done either by “grafting to” in which functionalized monomer react with backbone polymer to form

grafted one or “grafting from” in which substrate is treated with some method to generate immobilized initiators followed by polymerization. The “crosslinking” is irreversible process in which the association of polymers through a chemical bond occurs. It may be intra and intermolecular.

Grafting by chemical routes

In this method redox reagents are used which produce the free radicals. These free radicals are then used for grafting. The technique is simple to carry out, feasibility exists at room temperature and also the extent of grafting can be controlled by controlling the reaction variables like reaction time, temperature, monomer concentration.

The probable reaction pathways are described below.

With Fenton's reagent ($\text{Fe}^{2+} / \text{H}_2\text{O}_2$)

An hydroxyl radical is generated by the reaction of Fe^{2+} and H_2O_2 . The hydroxyl radical abstracts the hydrogen atom from the polymeric substrate, producing the free radical on it. The monomer molecules in the vicinity of the polymeric substrate become the acceptor of the radicals, which results in chain initiation. Thereafter, they become the free radical donors to the neighboring molecules. In this way, the grafted chains usually grow. These grafted chains terminate by coupling to yield the grafted copolymer [86]

(a) With Fe^{2+} / Persulphate: Persulphate and a ferrous ion act as a source of $\text{SO}_4^{\cdot -}$.

(b) With Persulphate and Reducing Agent: Persulphate and a reducing agent like, sodium bisulphite, thiosulphate, or Ag^+ are also the source of $\text{SO}_4^{\cdot -}$, which subsequently produces OH^{\cdot} .

(c) With Fe^{2+} / Hydroperoxides: Hydroperoxides and Fe^{2+} generate free radicals via thermal decomposition. The resulting $t\text{-BuO}^{\cdot}$ participates in hydrogen abstraction to generate OH^{\cdot} and the macro radical on the polymeric backbone.

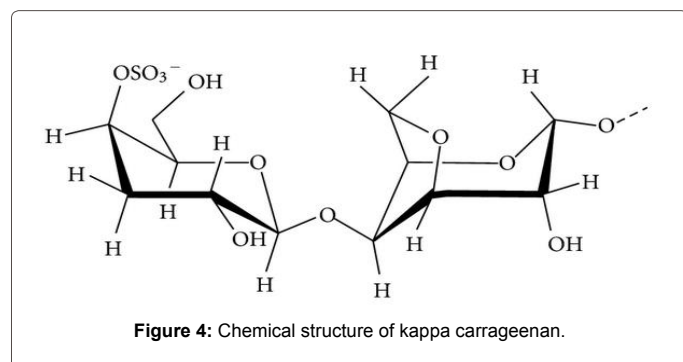
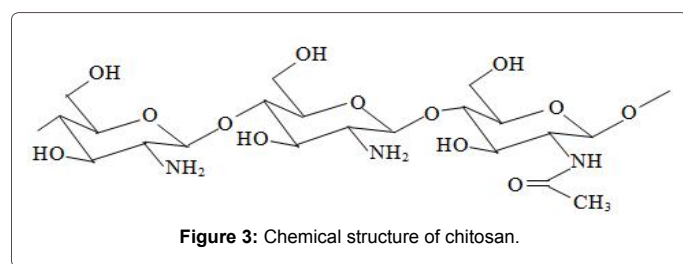
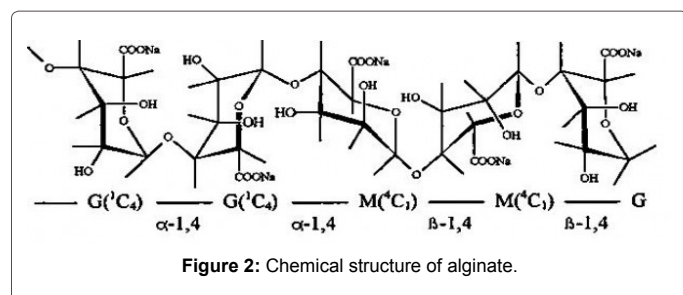
(d) By Direct Oxidation: In this method, unlike the above ones the radicals are generated on the backbone itself by use of transition metal ions (e.g., Ce^{4+} , Cr^{6+} , V^{5+} and Co^{3+}). The metal ions with low oxidation potential are the proper choices for the reaction. These highly reactive ions are responsible for initiating graft copolymerization.

(e) Using Metal Chelates: Controlling redox potential helps in avoiding unwanted reaction. This can be achieved by the use of metal chelates in the grafting reaction. The metal ion forming complex with the monomer decomposes to the free radical, which undergoes a chain transfer to the polymer.

(f) By Indirect Method: The secondary free radicals are generated in the system and may ultimately induce the free radical sites required for grafting [87].

Crosslinking

It also refers to use of different crosslinking agents and initiators; the mechanism is similar to the grafting reaction. In this chemical pretreatment (e.g., ozonation, diazotization, and xanthation) is done on the polymer backbone which generates free radicals that provide sites for grafting. It occurs till all monomers have been consumed. In these reactions $R_i < R_p$, where, as for the conventional free radical grafting, $R_i > R_p$ (R_i and R_p are the rate of initiation and propagation). Also dynamic equilibrium occurs between a propagating radical and dormant species. Predetermination of molar mass of the grafted/crosslinked polymer molecules is possible by use of osmometry and



small-angle laser light scattering [88]. Crosslinked sodium alginate and hydroxyl ethyl cellulose beads were used for controlled release of ibuprofen and diclofenac sodium [89].

Enzymatic technique

The graft and crosslinking reactions with the help of enzymes (i.e., biological proteinaceous catalyst) are the features of this technique. Oxidoreductase enzymes (horse-radish peroxidase, Tyrosinase, etc.) are focused in the literature as they are capable of forming free radicals (e.g., phenol/amine derivatives) by abstracting electrons or by supplying molecular oxygen to the molecules. The active species formed then either condenses each other or react with the nucleophiles the reactions are milder and there is less use of harsh chemicals. Initiation needs the enzyme to form the free radicals and is followed by non-enzymatic reactions. Enzyme selectivity and specificity makes the reaction simple and offers the potential for better controlling macromolecular structure without the need of protection or deprotection steps. It can be coupled with the other polymerization methods [90].

Applications of Derivatisation

Alginate

It is a water-soluble linear polysaccharide extracted from brown seaweed and is composed of alternating blocks of 1–4 linked L-glucuronic and D-mannuronic acid residues as shown in Figure 2. Some modifications of alginate for drug delivery are Alginate combined with

chitosan [90], thiolated alginate-albumin nanoparticles [91], alginate-polyoxamer microparticles, Hydrated thiolated alginate, alginate-poly (lactic-co-glycolic acid) nano/micro hydrogel matrices, chitosan-Ca-alginate microspheres, alginate modified by microenvironmental interaction with calcium ion, polyethylene glycol-anthracene modified alginate [92], photocrosslinked heparin-alginate hydrogels, alginate-guar gum hydrogel, Micelles/sodium- alginate composite gel beads [93], scleroglucan/alginate/borax gels [94], dual cross linked alginate [95].

Chitosan

The chemical structure of chitosan has been shown in Figure 3. Some modification of chitosan are carboxymethylation [96,97], carboxyethylation [98], reductive amination with phosphorylcholine glycerinaldehydes [99], sulfation [100], N- or O-acylation alkylation [101-104], quaternarization [105-107], thiolated chitosan [108], phosphorylated chitosan [109,110], grafted chitosan [111]. Chitosan phthalate is less hydrophilic than chitosan succinate. The relative pharmacological efficacy for chitosan phthalate and chitosan succinate microspheres was almost three-fold higher than the efficacy of the oral insulin administration [112]. Among viral and non-viral delivery vectors, the use of non-viral vectors such as chitosan or its derivatives is attractive, since these polymers are biodegradable, biocompatible, with low toxicity and high cationic potential. Even though much of the technology-base has been well established for targeted delivery of plasmid DNA using chitosan and its derivatives, only recently, has the technology been applied to the targeted delivery of si RNA [113]. Derivatives of chitosan have been used in development of micro and nanoparticles [114].

Carrageenans

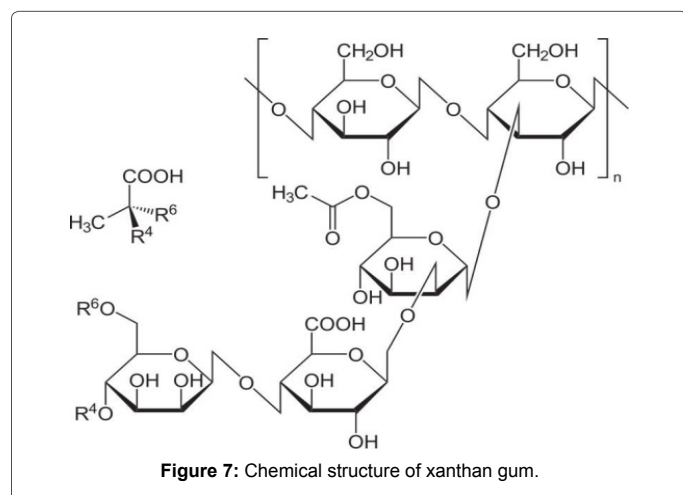
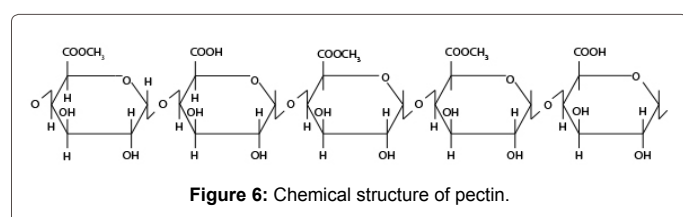
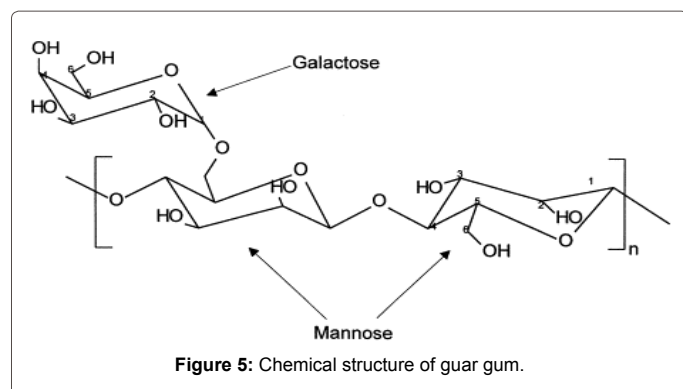
Figure 4 gives an idea about the structure of kappa carrageenan. Some modified forms of carrageenan for drug delivery is iota-carrageenan combined with locust bean gum [115], carrageenan combined with gellan gum [116], chitosan/carrageenan nanoparticles [117], agarose-carrageenan hydrogels [118]. Microencapsules with carrageenan-locust bean gum mixture in a multiphase emulsification technique for sustained drug release of gentamycin sulphate.

Guar gum

Guar gum is a galactomannan as shown in Figure 5. Several modifications of guar gum for drug delivery are graft copolymers of N-Vinyl-2-Pyrrolidone onto guar gum for sorption of Fe and Cl ions [119]. Graft copolymer of partially carboxymethylated guar gum-g-N-vinyl-2-pyrrolidone [120], Cross-linking of alginate guar gum with glutaraldehyde [121], carboxymethyl guar films for the formulation of transdermal therapeutic systems [122], graft copolymer H-partially carboxy methylated guar gum-g-methacrylic acid [123]. Complexation of cupric ion-guar gum-graft-acrylamide [124], yttrium crosslinked guar gum-g-acrylamide gel systems [125], Phosphated cross linked guar gum [126], polyester-guar gum/hydroxyl propyl guar gum [127]. Microspheres of Carboxymethyl Guar Gum used were for In Vitro Release of Abacavir Sulfate [128].

Pectin

The chemical structure of pectin has been mentioned in Figure 6. To achieve better drug delivery, certain modifications of pectin are done. These are Polyelectrolyte Complex (PEC) film between pectin as an anionic polyelectrolyte and chitosan as a cationic species [129] self-assembling pectin-liposome nano complexes [130], novel pectin-4-aminothiophenole conjugate microparticles [131], pectin/



HPMC polymer mixture [132]. Pectin-NH was prepared by modifying the galacturonic acids carboxyl groups with primary amine groups [133], amidated pectin derivatives with n-propyl-3-aminopropyl-3-propanol or 7-aminoheptyl-substituents [134], thiolated pectin [135], pectin/poly (lactide-co-glycolide) composite matrices [136], mixed pectin/ethylcellulose films, calcium cross-linked pectinate [137,138].

Xanthan gum

Figure 7 gives the chemical structure of xanthan gum. Some modifications of xanthan for drug delivery are gelatinized starch-xanthan gum hydrogel system, acrylamide-grafted-xanthan gum, Graft copolymerization of ethylacrylate onto xanthan gum, xanthan combined with Konjac glucomannan, xanthan combined with boswellia gum (3:1), xanthan gum combined with guar gum(10:20), xanthan gum combined with locust bean gum in 1:1 ratio [139]. Acrylamide-grafted-Xanthan Gum Copolymer Matrix Tablets were used for Oral Controlled Delivery of Antihypertensive Drugs [140].

Conclusion

Semi-synthetic polymers have wide application in pharmaceutical

field. There are numerous natural polymers available. Each of these polymers can be derivatised by different method. They show improved physicochemical properties along with the modification obtained by attachment of particular moiety. These derivatives of polymers can be used for development of many pharmaceutical drug delivery systems. There are several natural polymers which are yet to be derivatised. Thus there is great opportunity to the research /development scientist to develop novel polymers by modification of natural polymers.

Conflict of Interest

The author(s) declare(s) that there is no conflict of interests regarding the publication of this article.

Acknowledgement

Authors are very much thankful to Dr. P.S. Gide, Principal of Hyderabad Sindh National Collegiate Boards (HSNCB's) Dr. L. H. Hiranandani College of Pharmacy, Ulhasnagar for his continuous support, guidance and encouragement.

References

1. William BJ (2008) Ask the Historian: The origin of the polymer concept. *J Chem Edu* 88: 624-625.
2. Shukla RK, Tiwari A (2012) Carbohydrate polymers: Applications and recent advances in delivering drugs to the colon. *Carbohydr Polym* 88:399-416.
3. Liu Z, Jiao Y, Wang Y, Zhou C, Zhang Z (2008) Polysaccharides-based nanoparticles as drug delivery systems. *Adv Drug Deliv Rev* 60:1650-1662.
4. Saravanakumar G, Jo DG, Park JH (2012) Polysaccharide based nanoparticles: A versatile Platform for Drug Delivery and Biomedical Imaging. *Curr Med Chem* 19:3212-3219
5. Satturwar PM, Fulzele SV, Dorle AK (2003) Biodegradation and in vivo biocompatibility of rosin: A natural film-forming polymer. *AAPS Pharm Sci Tech* 4: 1-6.
6. Lam KS (2007) New aspects of natural products in drug discovery. *Trends Microbiol* 15: 279-89.
7. McChesney JD, Venkataraman SK, Henri JT (2007) Plant natural products: Back to the future or into extinction? *Phytochemistry* 68: 2015-2022.
8. Pandey R, Khuller GK (2004) Polymer based drug delivery systems for mycobacterial infections. *Current Drug Delivery* 1: 195- 201.
9. Chamarthy SP, Pinal R (2008) Plasticizer concentration and the performance of a diffusion-controlled polymeric drug delivery system. *Colloids And Surfaces A: Physicochemical and Engineering Aspects* 331: 25-30.
10. Alonso-Sande M, Teijeiro D, Remuñán- López C, Alonso MJ (2009) Glucomannan a promising polysaccharide for biopharmaceutical purposes. *Eur J Pharm Biopharm* 72: 453-62.
11. Guo J, Skinner GW, Harcum WW, Barnum PE (1998) Pharmaceutical applications of naturally occurring water-soluble polymers. *PharmSci TechnolToday* 1: 254-261.
12. Hirose K, Endo K, Hasegawa K (2004) A convenient synthesis of lepidimoide from okra mucilage and its growth-promoting activity in hypocotyls. *Carbohydrate polymers* 339: 9-19.
13. Ravi Kumar, Patil MB, Sachin Patil R, Mahesh S (2009) Evaluation of *Abelmoschus Esculentus* Mucilage as Suspending Agent in Paracetamol Suspension. *Intern J PharmTech Res* 1: 658- 665.
14. Ravi Kumar, Patil MB, Sachin Patil R, Mahesh S (2009) Evaluation of disintegrating properties of *Abelmoschus esculentus* mucilage. *Inter J Pharm Tech Res* 1: 241-246.
15. Ngwuluka NC, Idiakhwa BA, Nep EI, Ogajilan, Okafor IS (2010) Formulation and evaluation of paracetamol tablets manufactured using the dried fruit of *Phoenix dactylifera* Linn as an excipient. *Res Pharm Biotech* 2: 25-32.
16. Subas Chandra Dinda and Biswajit Mukharjee (2009) Gum cordia-A new tablet binder and emulsifier. *ActaPharmaceuticaScientia* 51: 189-198.
17. Khunkitti W, Aromdee C, Vorarat S, Chitropas P (2006) The potential of jackfruit starch for use as suspending agent and emulsifying agent. *Songklanakarinn J SciTech*.

18. Sabale V, Patel V, Paranjape A (2012) Isolation and characterization of jackfruit mucilage and its comparative evaluation as a mucoadhesive and controlled release component in buccal tablets. *Int J Pharm Investig* 2: 61-69.
19. Deveswaran R, Sindhu Abraham, Bharath S, Basavaraj BV, Sharon Furtado (2009) Design and Characterization of Diclofenac sodium tablets containing Tamarind seed polysaccharide as Release retardant. *Inter J PharmTech Res* 1191-195.
20. Mishra MU, Khandare JN (2011) Evaluation of tamarind seed polysaccharide as a biodegradable carrier for colon specific drug delivery. *Inter J Pharm Pharma Sci* 3: 139-142.
21. Ali N, Hossein N, Afagh K, Tarifeh S, Hadi V, Ford JL (2008) An in vitro evaluation of fenugreek mucilage as a potential excipient for oral controlled-release matrix tablet. *Drug Development and Industrial Pharmacy* 34: 323-329.
22. Malik K, Arora G, Singh I (2011) Locust bean gum as superdisintegrant—formulation and evaluation of nimesulide oral dispersible tablet. *Polimery wMedycynie* 41: 17-28.
23. Venkatarajua MP, Gowdaa DV, Rajeshb KS, Shivakumara HG (2007) Xanthan and locust bean gum (from *Ceratonia siliqua*) matrix tablets for oral controlled delivery of propranolol hydrochloride. *Asian J Pharm Sci* 2: 39-248.
24. Jenita JLL, Vijaya K, Suma R, Raj B, Siddiqua A (2010) Formulation and evaluation of compression coated tablets of mesalazine for colon delivery. *Inter J PharmTech Res* 2: 535-541.
25. Shin HJ, Ki MH, Yoon B, SW (2006) An, Gastricretentive controlled release mono matrix tablet. *Chong Kun Dang Pharmaceutical.Tech Rep.*
26. Uner M, Altinkurt T (2004) Evaluation of honey locust (*Gleditsia triacanthos* Linn.) gum as sustaining material in tablet dosage forms. *IlFarmaco* 59: 567-573.
27. Singh S, Bothara DSB, Singh S (2010) Pharmaceutical characterization of *Cassia tora* of seed mucilage in tablet formulations. *Schol Res Lib* 2: 54-61.
28. Mann AS, Jain NK, Kharya MD (2007) Evaluation of the suspending properties of *Cassia tora* mucilage on sulphadimidine suspension. *Asian J ExpSci* 21: 63-67.
29. Vendruscolo CW, Andrezza IF, Ganter JLMS, Ferrero C, Bresolin TMB (2005) Xanthan and galactomannan (from *M. scabrella*) matrix tablets for oral controlled delivery of theophylline. *Inter J Pharms* 296: 1-11.
30. Singh K, Kumar A, Langyan N and Ahuja M (2009) Evaluation of *Mimosa pudica* seed mucilage as sustained-release excipient. *AAPS PharmSciTech* 10: 1121-1127.
31. Chopra RN, Nayar SL, Chopra IC (1956). *Glossary of Indian Medicinal Plants* (1stedtn)
32. Sheth NS, Shah NV, Shah NC (2010) Extraction of mucilage from *Ocimum americanum* and its role as disintegrant in tablets formulation. *J Global Pharma Tech* 2: 26-31.
33. Pranshu Tangri, Satheesh Madhav NV, Shaffi Khurana (2011) Formulation of Paracetamol Suspension using A Novel Bio Anti-Settling agent from *Vigna mungo*. *Intern J PharmTech Res* 3: 1234-1237.
34. Basavaraj BV, Naramsetty S (2013) *Vigna Mungo* Mucilage - A Natural Polymer in the Design of Matrix Based SR Tablet of Aceclofenac. *Inter J Pharm Sci Res* 21: 125-130.
35. Kale RH, Joshi UM, Ambhore DP, Sitaphale GR (2009) Evaluation of Evaluation of *Delonix regia* Raf. Endospermic mucilage as tablet binder. *Inter J ChemTech Res* 1: 11-15.
36. Ashton WA, Jefferies M, Morley RG, Pass G, Phillips GO, Power DMJ (1975) Physical properties and applications of aqueous solutions of *Albizia zygia* gum. *J Sci Food Agri* 26: 697-704.
- Odeku OA, Fell JT (2005) In-vitro evaluation of khaya and albizia gums as compression coatings for drug targeting to the colon. *J Pharm Pharmacol* 57: 163-168.
38. Sarojini S, Kunam SD, Manavalan R, Jayanthi B (2010) Effect of natural gum as a binder in the formulation of diclofenac sodium tablets. *Inter J Pharm Sci Res* 1: 55-60.
39. daSilveira Nogueira Lima R, Rabelo Lima J, Ribeiro De Salis C, de Azevedo Moreira R (2002) Cashew-tree (*Anacardium occidentale* L.) exudate gum: a novel bioligand tool. *BiotechnolApplBiochem* 35: 45-53.
40. Kumar R, Patil MB, Patil SR, Paschapur MS (2009) Evaluation of *Anacardium occidentale* gum as gelling agent in aceclofenac gel. *Inter J PharmTech Res* 1: 695-704.
41. Ofori-Kwakye K, Asantewaa Y, Kipo SL (2010) Physicochemical and binding properties of cashew tree gum in metronidazole tablet formulations. *Inter J Pharm Pharm Sci* 2: 105-109.
42. Panda D, Swain S, Gupta R, Si S, Kanungo SK (2006) Preparation and evaluation of gels from gum of *Moringa oleifera*. *Ind J Pharm Sci* 68: 777-780.
- Panda DS, Choudhury NS, Yedukondalu M, Si S, Gupta R (2008) Evaluation of Gum of *Moringa oleifera* as a Binder and Release Retardant in Tablet Formulation. *Indian J Pharm Sci* 70: 614-618.
44. Patel BV, Patel D (2011) Study of disintegrant property of *Moringa Oleifera* gum and its comparison with other superdisintegrants. *Inter J ChemTech Res* 3: 1119-1124.
45. Morkhade DM, Fulzele SV, Satturwar PM, Joshi SB (2006) Gum copal and gum damar: novel matrix forming materials for sustained drug delivery. *Ind J Pharma Sci* 68: 53-58.
46. Morkhade DM and Joshi SB (2007) Evaluation of gum damar as a novel microencapsulating material for ibuprofen and diltiazem hydrochloride. *Indian J Pharm Sci* 69: 263-268.
47. Osete-Cortina L, Domenech-Carbo MT (2005) Analytical characterization of diterpenoid resins present in pictorial varnishes using pyrolysis-gas chromatography-mass spectrometry with on line trimethylsilylation. *J Chromatog A* 1065: 265-278.
48. Umekar MJ, Yeole PG (2008) Characterization and evaluation of natural copal gum-resin as film forming material. *Intern J Green Pharm* 2: 37-42.
49. Janaki B, Sashidhar RB (2000) Subchronic (90-day) toxicity study in rats fed gum kondagogu (*Cochlospermum gossypium*). *Food Chem Toxicol* 38: 523-534.
50. Murthy KVR, Subramanyam GSV (2008) Design and Statistical Optimization of Hupu Gum Based Gastric Floating Drug Delivery Systems of Diltiazem HCl. *American Ass Pharma Sci, Atlanta, Ga, USA.*
51. Krishna RR, Murthy TEGK (2010) Preparation and evaluation of mucoadhesive microcapsules of glipizide formulated with gum kondagogu: In vitro and in vivo. *Acta Pharmaceutica Scientia* 52: 335-344.
52. Nayak BS, Nayak UK, Patro KB, Rout PK (2008) Design and evaluation of controlled release bhara gum microcapsules of famotidine for oral use. *Research Journal of Pharmacy and Technology* 1: 433-436.
- Eagles PF, Stephen AM, Churms SC (1993) Molecular structures of gum exudates from *Hakea* species. *Phytochemistry* 34: 709-713.
54. Alur HH, Pather SI, Mitra AK, and Johnston TP (1999) Evaluation of the gum from *Hakea gibbosa* as a sustained-release and mucoadhesive component in buccal tablets. *Pharm Develop Technol* 4: 347-358.
55. Okafor IS, Chukwu A, Duala K (2001) Some physicochemical properties of grewia gum, Nigeria. *J Polym Sci Tech* 2: 161-167.
56. Martins E, Christiana I, and Olobayo K (2008) Effect of *Grewia* gum on the mechanical properties of Paracetamol tablet formulations. *Afr J Pharm Pharmacol* 2: 1-6.
57. Nep EI and Conway BR (2010). Polysaccharide gum matrix tablets for oral controlled delivery of cimetidine. *J Pharm Sci Res* 2: 708-716.
58. Ogaji I, Okafor IS (2011) Potential of *Grewia* gum as film coating agent: some physicochemical properties of coated praziquantel tablets. *Inter J Pharm Res* 3: 16-19.
59. Muzib YI, Kurri PS (2011) Formulation and evaluation of gum olibanum-based sustained release matrix tablets of ambroxol hydrochloride, *Inter J Pharm Pharmaceu Sci* 3: 195-199.
60. Prasanthi NL, Manikiran SS, Rao NR (2011) In vitro drug release studies of ziprasidone from tablets using natural gums from biosphere. *Archives App Sci Res* 3: 513-519.
61. Chowdary KPR, Mohapatra P, Krishna MNM (2008) Evaluation of olibanum resin as microencapsulating agent for controlled drug delivery. *Rasayan J Chem* 1: 99-104.
62. Bamiro OA, Sinha VR, Kumar R, Odeku OA (2010) Characterization and

- evaluation of Terminaliarandii gum as a binder in carvedilol tablet formulation. *Acta Pharmaceutica Scientia* 52: 254–262.
63. Rao KM, Gnanaprakash K, Badarinath AV (2010) Preparation and evaluation of flurbiprofen gel; mucilage of *Coccolushirsutus* leaf powder as gel base. *Inter J PharmTech Res* 2: 1578–1583.
64. Choi S, Chung MH (2003) A review on the relationship between Aloe vera components and their biologic effects, *Seminars in Integrative Medicine* 1: 53–62.
65. Ahad AH, Kumar CS, Kumar B (2010) Development and in vitro evaluation of glibenclamide Aloe barbadensis miller leaves mucilage controlled release matrix tablets. *Inter J PharmTech Research* 2: 1018–1021.
66. Jenita JLL, Vijaya K, Suma R, Raj B (2010) Formulation and evaluation of compression coated tablets of mesalazine for colon delivery. *Inter J PharmTech Res* 2: 535–541.
67. Janiand GK, Shah DP (2008) Assessing *Hibiscus rosa-sinensis* Linn as an excipient in sustained-release tablets. *Pharm Tech* 32: 62–75.
68. Gangurde AB, Malode SS, Bhambar RS (2008) Preliminary evaluation of neem gum as tablet binder. *Ind J Pharm Edu Res* 42: 344–347.
69. Abdul AH, Suresh KC, Kumar BA (2010) Permeation studies of diclofenac sodium from ficus carica fruit mucilage matrices for transdermal delivery. *Intern J ChemTech Res* 2: 937–941.
70. Venkaiah K, Shah JJ (1984) Distribution, development and structure of gum ducts in *Lanneacoromandelica* (Houtt.) merril. *Annals of Botany* 54: 175–186.
71. Paul J (1953) Principles of Polymer Chemistry. The George Fisher Baker Non-Resident Lectureship in Chemistry at Cornell University, Cornell University Press, USA, 39.
72. Dav'e V, McCarthy SP (1997) Review of konjacglucomannan, *J Environ Polym Degr* 5:237–241.
73. Alvarez-Manceñido F, Landin M, Ilacik I, Martínez-Pacheco R (2008) Konjacglucomannan and konjacglucomannan/xanthan gum mixtures as excipients for controlled drug delivery systems, *Inter J Pharm*, 349:11–18.
74. Gurpreet Arora, KaranMalik, Inderbir Singh (2011) Formulation and Evaluation of Mucoadhesive Matrix Tablets of Taro Gum: Optimization Using Response Surface Methodology, *Polimery w Medycynie* 41:23-34.
75. Dodi G, Hritcu D, PopaMI (2011) Carboxymethylation of guar gum: synthesis and characterization. *Cellulose Chemistry Tech* 45: 171–176.
- Chourasia MK, Jain SK (2004) Polysaccharides for colon targeted drug delivery. *Drug Deliv* 11: 129-148.
77. Edgar K (2004) Organic cellulose esters. In: Mark HF (ed) *Encyclopedia of polymer science and technology*, Wiley, New York: NY: 9: 129–158.
78. Chen YL (2008) Preparation and characterization of water soluble chitosan gel for skin hydration. Mph thesis. Univ Sains Malaysia 1-181.
- Zhang Q, Li N, Liu X, Zhao Z, Li Z, et al. (2004) The structure of a sulfated galactan from *Porphyrhaitanensis* and its in vivo antioxidant activity. *Carbohydr Res* 339: 105-111.
80. Dutta PK, Dutta J, Tripathi VS (2004) Chitin and Chitosan: Chemistry, properties and application. *J sci ind res* 63: 20-31.
81. Martindale's (2009) *The complete Drug Reference*, Pharmaceutical press I: 442.
82. Gautier SJ, Lecourtier (1991) *Polym. Bull. (Berlin)* 26: 41.
83. Hatada, Kitayama (2006) *NMR Spectroscopy of Polymers*, ISBN: 3-540-40220-9, Springer Laboratory Manuals in Polymer Science,
84. Prabhanjan H, Gharia MM, Srivastava HC (1989) Guar gum derivatives. Part I: preparation and properties. *Carbohydr Polym* 11: 279–292.
85. Lapasin R, Prici S, Tracaneli P (1991) Rheology of hydroxyethyl guar gum derivatives. *Carbohydrate Polym* 14: 411–427.
86. Fenton HJH (1894) Oxidation of tartaric acid in presence of iron. *J Chem Soc Trans* 65: 899–911.
87. Pепенzhik MA, Virnik AD, Rogovin ZA (1969) Synthesis of graft cellulose copolymers and calcium salt of poly (acrylic acid), *VysokomolSoedinSer B* 11: 245–250.
88. Stepto RFT, Gilbert RG, Hess M, Jenkins AD, Jones RG, et al. (2009) *Dispersity in Polymer Science*. *Pure App Chem*81: 351–353.
89. Krishna Rao KSV, Subha MCS, Vijaya Kumar Naidu B, Sairam MN, Mallikarjuna N, et al. (2006) Controlled Release of Ibuprofen and Diclofenac Sodium through the Beads of Sodium Alginate and Hydroxy Ethyl Cellulose Blends. *J. Appl. Polym. Sci*, 102: 5708-5718.
90. Amit B, James W. Rawlins Paramita Ray (2008) *Polymer grafting and crosslinking*, Published by John Wiley & Sons, Inc., Hoboken, New Jersey page numbers: 20-23.
- George M1, Abraham TE (2006) Polyionic hydrocolloids for the intestinal delivery of protein drugs: alginate and chitosan--a review. *J Control Release* 114: 1-14.
92. Martinez, Iglesias I, Lozanob R, Teijon J, Blanco M (2011) Synthesis and characterization of thiolated alginate-albumin nanoparticles stabilized by disulfide bonds. Evaluation as drug delivery systems *Carbohydr Polym* 83: 1311-21.
- Wells LA, Sheardown H (2011) Photosensitive controlled release with polyethylene glycol-anthracene modified alginate. *Eur J Pharm Biopharm* 79: 304-313.
94. Huang X, Xiao Y, Lang M (2011) Micelles/sodium-alginate composite gel beads: a new matrix for oral drug delivery of indomethacin. *Carbohydr Polym*. 87: 790-798.
- Matricardi P, Onorati I, Coviello T, Alhaique F (2006) Drug delivery matrices based on scleroglucan/alginate/borax gels. *Int J Pharm* 316: 21-28.
96. Gong R, Li C, Zhu S, ZhangY, DuY, et al. (2011) A novel pH-sensitive hydrogel based on dual cross linked alginate/N- glutaric acid chitosan for oral delivery. *J Cont Rel* 85: 869-874.
97. Lu G, Kong L, Sheng B, Wang G, Gong Y, et al. (2007) Degradation of covalently cross-linked carboxymethyl chitosan and its potential application for peripheral nerve regeneration. *Eur Polym J* 43: 3807-3818.
98. Jiang H, Wang Y, Huang Q, Li Y, Xu C, et al. (2005) Biodegradable hyaluronic acid/N-carboxyethyl chitosan/protein ternary complexes as implantable carriers for controlled protein release. *Macromol Biosci* 5: 1226-1233.
99. Tiera MJ, Qiu XP, Bechaouch S, Shi Q, Fernandes JC, et al. (2006) Synthesis and characterization of phosphorylcholine-substituted chitosans soluble in physiological pH conditions. *Biomacromolecules* 7: 3151-3156.
100. Zhang C, Qu G, Sun Y, Wu X, Yao Z, et al. (2008) Pharmacokinetics, biodistribution, efficacy and safety of N-octyl-O-sulfate chitosan micelles loaded with paclitaxel. *Biomaterials* 29: 1233-1241.
101. Félix L, Hernández J, Argüelles-Monal WM, Goycoolea FM (2005) Kinetics of gelation and thermal sensitivity of N-isobutryl chitosan hydrogels. *Biomacromolecules* 6: 2408-2415.
102. Badawy ME, Rabea EI, Rogge TM, Stevens CV, Smaghe G, et al. (2004) Synthesis and fungicidal activity of new N,O-acyl chitosan derivatives. *Biomacromolecules* 5: 589-595.
103. Zhu A, Shan B, YuanY, Shen J (2003) Preparation and blood compatibility of phosphorylcholine- bonded O-butrylchitosan. *Polymer International* 52: 81-85.
104. Kubota N, Tatsumoto N, Sano T, Toya K (2000) A simple preparation of half N-acetylated chitosan highly soluble in water and aqueous organic solvents. *Carbohydr Res* 324: 268-274.
105. Kang HM, Cai YL, Deng JJ, Zhang HJ, Liu YF, Tang PS (2006) Synthesis and aqueous solution behavior of phosphonate functionalized chitosans. *Eur Poly J* 42: 2678-2685.
106. Huang RH, Chen GH, Sun MK, Hu YM, Gao CJ (2007) Preparation and characterization of quaternized chitosan/poly (acrylonitrile) composite nanofiltration membrane from epichlorohydrin cross-linking. *Carbohydr Polym*70: 318-323.
107. Murata JI, Ouchi YC, Ohya T (1996) Possibility of application of quaternary chitosan having pendant galactose residues as gene deliverytool. *Carbohydr Polym* 29: 69-74.
108. Sashiwa, H, Kawasaki N, Nakayama A (2003) Chemical modification of chitosan. Part 15: Synthesis of novel chitosan derivatives by substitution of hydrophilic amine usingN-carboxyethyl chitosan ethyl ester as an intermediate. *Carbohydr Res* 338: 557-561.
109. Bernkop-Schnürch A, Hornof M, Zoidl T (2003) Thiolated polymers--thiomers:

- synthesis and in vitro evaluation of chitosan-2-iminothiolane conjugates. *Int J Pharm* 260: 229-237.
110. Sakairi N, Shirai A, Miyazaki SH (1998) Surface and Interface-New Functions of Biorelated Polymers I. Synthesis and Properties of Chitin Phosphate. *Kobunshi Ronbunshu (Jap J Polym Sci Technol)* 55: 212-213.
111. Gulay B, Meltem Y, Yakup AM (2003) Affinity dye-ligand poly(hydroxyethyl methacrylate)/chitosan composite membrane for adsorption lysozyme and kinetic properties. *Biochem Eng J* 13:35-42.
112. Rudzinski WE, Aminabhavi TM (2010) Chitosan as a carrier for targeted delivery of small interfering RNA. *Int J Pharm* 399: 1-11.
113. Agnihotri SA, Mallikarjuna NN, Aminabhavi TM (2004) Recent advances on chitosan-based micro- and nanoparticles in drug delivery. *J Control Release* 100: 5-28.
114. Ubaidulla U, Khar RK, Ahmad FJ, Tripathi P (2009) Optimization of chitosan succinate and chitosan phthalate microspheres for oral delivery of insulin using response surface methodology. *Pharm Develop Technol* 14: 96-105.
115. Suzuki S, Lim JK (1994) Microencapsulation with carrageenan-locust bean gum mixture in a multiphase emulsification technique for sustained drug release. *J Microencapsul* 11: 197-203.
116. Rodriguez-Hernandez AI (1999) Dynamic visco elasticity behaviour of Igellan-Carrageenan and gellan-Xanthan gels. *Food hydrocolloids*. 13: 59-64.
117. Tapia C, Corbalan V, Costa E, Gai M, Yazdani-Pedram M (2005) Study of the release mechanism of diltiazem hydrochloride from matrices based on chitosan-alginate and chitosan-carrageenan mixtures. *Biomacromolecules* 6: 2389-2395.
118. Sjoberg H, Persson S, Caram-Lelham N (1999) How interactions between drugs and agarose-carrageenan hydrogels influence the simultaneous transport of drugs. *J Cont Rel* 59:391-400.
119. Sharma RL (2011) Synthesis and characterization of graft copolymers of N-Vinyl-2-Pyrrolidone onto guar gum for sorption of Fe²⁺ and Cr⁶⁺ ions. *Carbohydr Polym* 83: 1929-1936.
120. Mishra MM, Yadav M, Mishra D, Behari K (2011) Synthesis of graft copolymer (CMG-OH-g-NVP) and study of physicochemical properties: Characterization and application. *Carbohydr Polym* 83: 1749-1756.
121. Rana V, Rai P, Tiwary A, Singh R, Kennedy J, et al. (2011) Modified gums: Approaches and applications in drug delivery. *Carbohydr Polym* 83: 1031-1047.
122. Narasimha Murthy S, Hiremath SR, Paranjothy KL (2004) Evaluation of carboxymethyl guar films for the formulation of transdermal therapeutic systems. *Int J Pharm* 272: 11-18.
123. Yadav M, Dinesh, Mishra D, Behari K (2011) Synthesis of partially hydrolyzed graft copolymer (H-partially carboxymethylated guar gum-g-methacrylic acid): A superabsorbing material. *Carbohydr Polym* 85: 29-36.
124. Chattopadhyay A, Bhattacharya D, Singh R (1993) Reversible gel formation induced by ion complexation involving a cupric-ion-guar gum-graft-acryl amide interaction. *Carbohydr Polym* 17: 179-186.
125. Chattopadhyay A, Bhattacharya D, Singh R (1995) Studies on the physicochemical nature of yttrium and cupric ion cross linked guar gum-g-acrylamide gel systems. *Carbohydr Polym* 25: 277-283.
126. Gliko-Kabir I, Yagen B, Baluom M, Rubinstein A (2000) Phosphated crosslinked guar for colon-specific drug delivery. II. In vitro and in vivo evaluation in the rat. *J Control Release* 63: 129-134.
127. Anita G, Sullad, Lata S, Manjeshwar, Tejraj M, et al. (2011) Microspheres of Carboxymethyl Guar Gum for In Vitro Release of Abacavir Sulfate: Preparation and Characterization. *J App Polym Sci* 122: 452-460.
128. Shenoy M, D'Melo D (2007) Evaluation of mechanical properties of unsaturated polyester-guar gum/hydroxypropyl guar gum composites. *J Pharm Pharmaceut Sci* 1: 622-628.
129. Ghaffari A, Navaee K, Oskoui M, Bayati K, Rafiee-Tehrani M (2007) Preparation and characterization of free mixed-film of pectin/chitosan/Eudragit RS intended for sigmoidal drug delivery. *Eur J Pharm Biopharm* 67: 175-186.
130. Thirawong N, Thongborisute J, Takeuchi H, Sriamornsak P (2008) Improved intestinal absorption of calcitonin by mucoadhesive delivery of novel pectin-liposome nanocomplexes. *J Control Release* 125: 236-245.
131. Perera G, Barthelmes J, Bernkop-Schnürch A (2010) Novel pectin-4-aminothiophenole conjugate microparticles for colon-specific drug delivery. *J Control Release* 145: 240-246.
132. Ugurlu T, Turkoglu M, Gurer US, Akarsu BG (2007) Colonic delivery of compression coated nisin tablets using pectin/HPMC polymer mixture. *Eur J Pharm Biopharm* 67: 202-210.
133. Katav T, Liu L, Traitel T, Goldbart R, Wolfson M, et al. (2008) Modified pectin-based carrier for gene delivery: cellular barriers in gene delivery course. *J Control Release* 130: 183-191.
134. Šimkovič, I, Kováč J (2009) Amidated pectin derivatives with n-propyl-, 3-aminopropyl-, 3-propanol- or 7-aminoheptyl-substituents. *Carbohydr Polym* 76: 602-606.
135. Sharma R, Ahuja M (2011) Thiolated pectin: Synthesis, characterization and evaluation as a mucoadhesive polymer. *Carbohydr Polym* 85:658-663.
136. Liu L, Won YJ, Cooke PH, Coffin DR, Fishman ML, et al. (2004) Pectin/poly(lactide-co-glycolide) composite matrices for biomedical applications. *Biomaterials* 25: 3201-3210.
137. Bose A, Elyagoby A, Wong TW (2014) Oral 5-fluorouracil colon-specific delivery through in vivo pellet coating for colon cancer and aberrant crypt foci treatment. *Int J Pharm* 468: 178-186.
138. Hiorth M, Versland T, Heikkilä J, Tho I, Sande SA (2006) Immersion coating of pellets with calcium pectinate and chitosan. *Int J Pharm* 308: 25-32.
139. Sreenivasa Rao B, Prasanna RY, Mary S (2000) Design and studies of gum karaya matrix tablet. *Inter J Pharm Exp* 239-242.
140. Raghavendra C, Mundargi, Sangamesh AP, Tejraj M, Aminabhavi (2007) Evaluation of Acrylamide-grafted-Xanthan Gum Copolymer Matrix Tablets for Oral Controlled Delivery of Antihypertensive Drugs, *Carbohydr Polym* 69: 130-141.

Citation: Pawar HA, Kamat SR, Choudhary PD (2015) An Overview of Natural Polysaccharides as Biological Macromolecules: Their Chemical Modifications and Pharmaceutical Applications. *Biol Med (Aligarh)* 6: 224. doi: [10.4172/0974-8369.1000224](https://doi.org/10.4172/0974-8369.1000224)

Submit your next manuscript and get advantages of OMICS Group submissions

Unique features:

- User friendly/feasible website-translation of your paper to 50 world's leading languages
- Audio Version of published paper
- Digital articles to share and explore

Special features:

- 300 Open Access Journals
- 25,000 editorial team
- 21 days rapid review process
- Quality and quick editorial, review and publication processing
- Indexing at PubMed (partial), Scopus, EBSCO, Index Copernicus and Google Scholar etc
- Sharing Option: Social Networking Enabled
- Authors, Reviewers and Editors rewarded with online Scientific Credits
- Better discount for your subsequent articles

Submit your manuscript at: <http://www.omicsonline.org/submission>