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**A RECENT UPDATE ON MODIFICATION OF POLYSACCHARIDE AND ITS  
DIVERSE SIGNIFICANT UTILITIES IN PHARMACEUTICAL FIELD**

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**Abstract**

Graft copolymerization is one of the most promising techniques to modify the properties of naturally available polymers with a minimum loss in their native characteristics. Graft copolymerization is a very significant technique to add hybrid properties in backbone of polymers. The grafting generally initiated through the formation of free radical centers on the polymer backbone as well as monomer. Grafted polysaccharides have various applications in different important scientific areas such as drug delivery, pharmaceutical field, plastic industry, waste water treatment, tannery effluent treatment, textile industry, agriculture area, etc. all of this fascinated us to summarize the major research articles over the last two decades outlining different methods of grafting, surface modification, graft copolymerization of synthetic and natural polymers. Various redox initiator systems *viz.* ceric ammonium nitrate, persulfate, Irradiation, FAS-H<sub>2</sub>O<sub>2</sub> etc. is also explored for grafting of vinyl through conventional and non-conventional techniques.

**Keywords:** Polysaccharides, Grafting, Copolymer.

**Introduction**

Polysaccharides have plentiful abundance in the forest, plants, trees, sea shells and microbial resources, either from exudates, seed or agricultural crops. Some useful polysaccharides can be produced by biotechnical routes [1]. Natural polysaccharides and their derivatives are very useful for controlled release of drug in pharmaceutical and biomedical fields [2]. These are advantageous for controlled drug delivery systems, particularly for prolonged time-release of

drug enhancement of the activity of labile drugs due to their protection against hostile environments [3].

The polysaccharides hold an advantage over the synthetic polymers because of non-toxicity less cost, biodegradability, and easy availability to their synthetic counterparts. Polysaccharides appear as a very appealing alternative of substitution because they are renewable raw materials [4]. Natural polysaccharides possess many unique properties, but due to some shortcomings simultaneously, particularly shelf life and prone to bacterial attack have limited scope as long-lasting materials. Some synthetic polymers are biodegradable and can be tailor-made easily. Therefore, by composing the individual advantages of polysaccharide and synthetic polymers better shelf life and biodegradability can be achieved. Starch-based derivatives completely biodegradable polymers and have potential applications in biomedical and environmental fields [5]. Polysaccharides, proteins and nucleic acids are basic components in living organic systems. Therefore biopolymers mimicking synthetic polymers have great scope in current and future research to meet out the industrial and scientific requirements. The synthetic polymers can be divided into different categories based on their chemical properties. Some special types of polymers have a high category as a very useful class of polymers and have their own special chemical properties and applications in various areas. These polymers are coined with different names based on their physical or chemical properties of stimuli-responsive polymers [6]. Graft copolymerization is a significant technique to add the advanced properties of backbone polymers. It is a chemical technique which modifies the desired features in natural fiber without affecting their inherent behavior. Many researchers have carried out the grafting onto the different polysaccharide backbone using various vinyl monomers, and using a wide range of initiator, an oxidizing agent, monomers, binary vinyl monomeric mixtures and radiation techniques and achieved fruitful results [8-9]. One of the most effective ways of modification of psyllium is by graft copolymerization with suitable monomers [10-14], and the properties of the grafted product can be suitably modulated in terms of percentage grafting. The end product macromolecules are thus tailored at the molecular level for desired applications [15]. Graft copolymerization of vinyl monomers is a universal, effective and accessible method of chemical modification in graft molecules in the natural polymer. Considerable work is on graft copolymerization of a natural polysaccharide such as starch, chitosan, cellulose etc. with the vinyl monomers [16- 17]. Copolymerization is done to improve the properties and the utility of a

system in various applications. It allows the synthesis of the almost unlimited amount of different products by variation in nature and the relative amount of the monomer units in the copolymer. Copolymerization modifies the symmetry of the polymeric chain and modulates both intramolecular forces and properties such as glass transition temperature, crystallinity, solubility, elasticity, permeability and chemical reactivity can be tuned within wide limits. Graft copolymers are prepared by polymerizing a monomer in the presence of a polymer of different backbone chain. Grafting results into retention of desirable properties of base polymer and incorporation of favorable properties in grafted polymer.

Graft copolymer synthesis is important for the development of polymer science with potential uses in areas such as composites, medical applications, fiber modifications etc. Product characterizations are vital in developing structure-property relationships. Radical polymerizations is a useful method for the polymerization of a wide variety of vinyl monomers and can be plagued by a lack of control over the mechanism, radical polymerizations have many different reactions occurring simultaneously namely initiation, propagation, termination by coupling, disproportionate or chain transfer. Extending the versatility of radical polymerizations and radical graft copolymerization has been successful in terms of obtaining a grafted derivative, however, grafted product characterizations are being inherently difficult as it is further complicated by homopolymer which is amply generated during the reaction [17]. The main aim of this review is to survey the literature on polysaccharides particularly focused on its graft copolymer methods by using the different initiator and their applications in drug delivery, pharmaceutical field, plastic industry, waste water treatment, tannery waste water treatment, and textile industry.

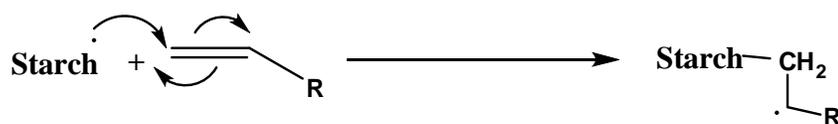
Graft copolymers are biodegradable with advanced property and are used in agriculture, textile, paper industry, medical treatment and in the petroleum industry as flocculants and thickening agents. Graft copolymerization can be done with or without the presence of different initiator systems by conventional and non-conventional methods [18].

### **Different systems of initiation**

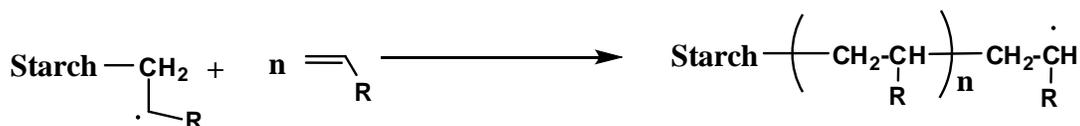
Graft copolymerization can be obtained by different initiator systems among them azobisisobutyronitrile (ABIN), ammonium persulfate, potassium persulfate (KPS), ceric ammonium nitrate (CAN), and benzoyl peroxide, ceric ammonium nitrate is widely used for the

synthesis of graft copolymers [18].investigated that the irradiation of polymer can cause hemolytic fission and thus forms free radicals on the polymer backbone. The medium is necessarily in the radiation technique, e.g. if irradiation is carried out in the air, peroxides may be formed of the polymer shown in fig. 1a-b. However, the life of the free radical depends upon the nature of the polymer.

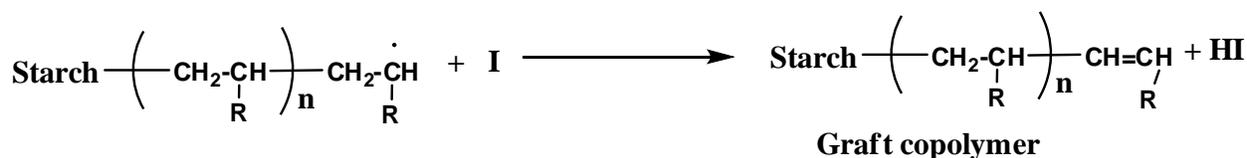
### Initiation step



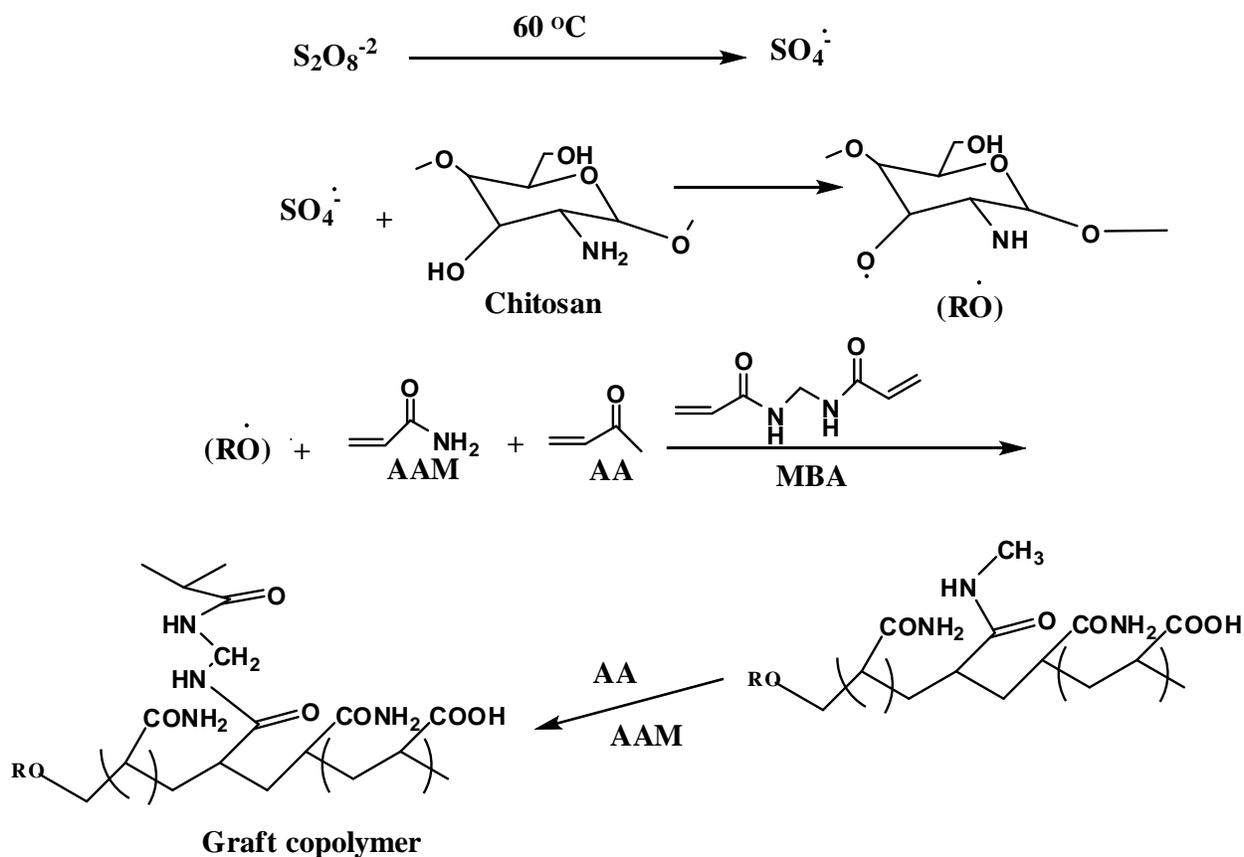
### Propagation step



### Termination step



**Fig.1a.** Free radical mechanism of graft copolymerization of vinyl monomer B onto starch.



**Fig.1b. General Mechanism for radical graft polymerization of acrylamide and acrylic acid onto chitosan in the presence of MBA crosslinker.**

A graft copolymer is a macromolecular chain with one or more species of block connected to the main chain as side chain(s). Thus, it can be described as having the general structure, where the main polymer backbone, commonly referred to as the trunk polymer, has branches of another polymeric chain emanating from different points along its length. Various methods of graft copolymerization have been reported in the literature [19-25].

#### *Different system /mode of initiation*

##### *Ceric Ion Initiation*

Nayak et al. investigated that ceric ion-induced redox initiation method has been preferred for grafting polymerization because the redox process initiates free radical sites exclusively on the polysaccharide backbone, which reduces the homopolymerization of participating monomers [27].

Cerium is a member of the group IIIA of the periodic table. Cerium is a tetravalent atom and has two common oxidation states +3 Ce(III) and +4 Ce(IV).



In most of the homogeneous oxidation of the substrate by  $\text{Ce}^{+4}$ (IV), the formation of the intermediate complex has been found to be an important prerequisite. Typically ceric ion initiation is performed under acidic aqueous conditions. Acid concentration has affected the rate of polymerization initiated by the ceric ion, but the relationship is empirical. For instance, the following equilibrium is shown in the following equation is observed in aqueous perchlorate acid solutions, where the ceric ion concentration is dependent upon the acid concentration.



Generally, aqueous ceric ion initiations are performed under acidic conditions to promote the higher concentration of Ce(IV) [28-29]. Sadeghi et al, studied on polymethacrylate grafted onto carboxymethyl cellulose (CMC) backbone in a homogeneous solution using a ceric ammonium nitrate (CAN) as an initiator and water as solvent [30].

Chauhan A. et al. 2013 synthesized Bioremediation of Natural Fiber by Graft Copolymerization. And also studied the Sorrel stem fiber was graft copolymerized by vinyl monomeric mixtures that lead to an increase in the percentage grafting with a significant change in physical-chemical-thermal resistance. Miscibility in organic solvents, hydrophobicity was found to increase whereas crystallinity, crystallinity index, dye-uptake, and hydrophilicity decreased after graft copolymerization. According to Chauhan A. et al. Grafting of a vinyl monomer onto the polymeric backbone occurred as follows (Fig. 2) [31].

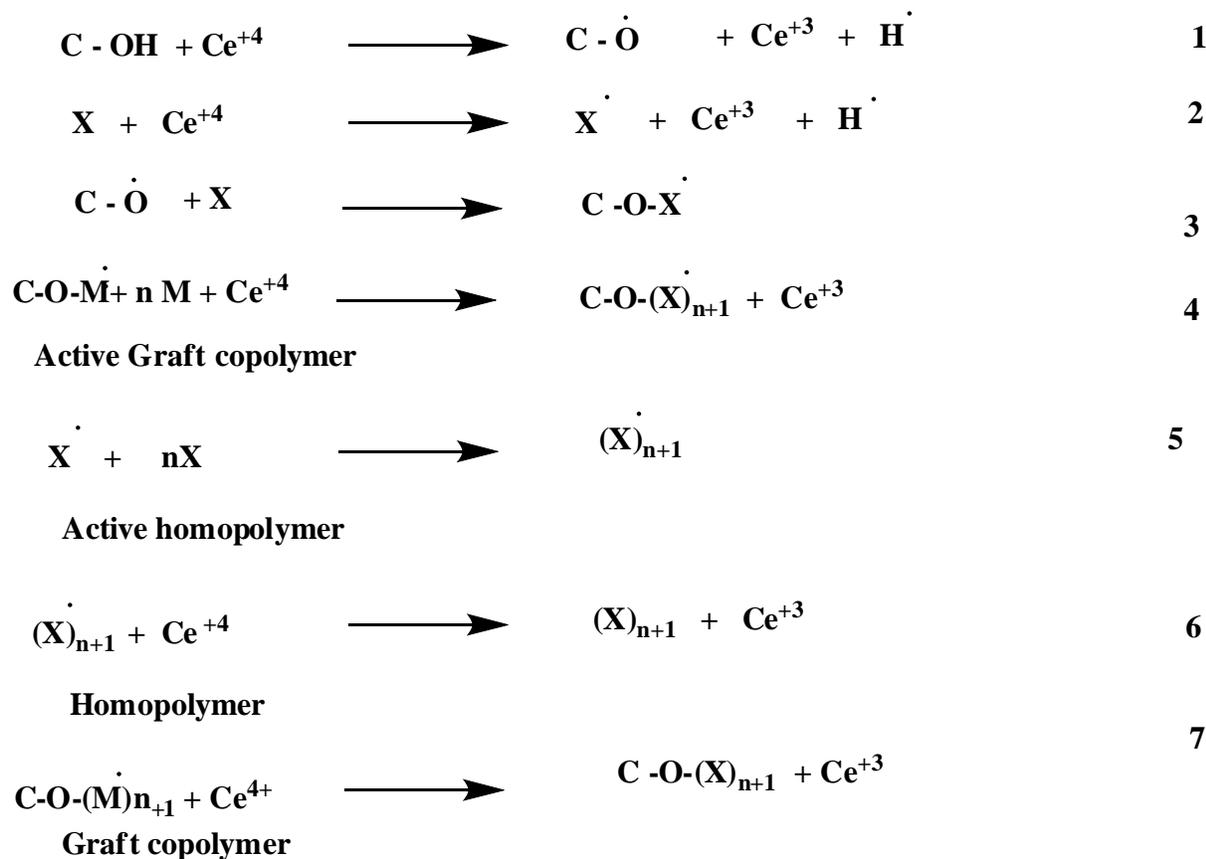


Fig. 2. - Bioremediation of Natural Fiber by Graft Copolymerization.

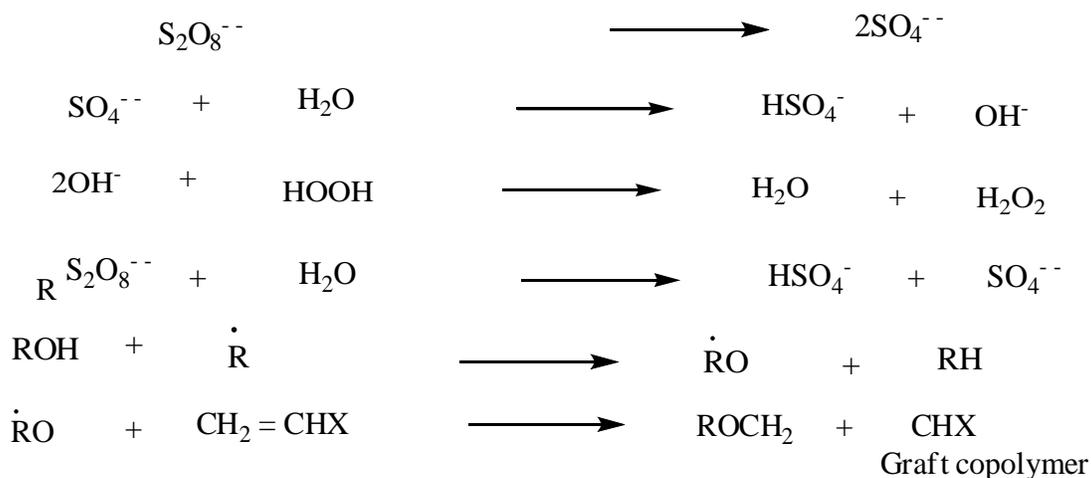
Where, C-OH = sabdariffabackbone and M = monomer

Ikhuria et al, synthesized graft copolymerization of acrylonitrile onto cassava starch by ceric ion induced initiation [32]. Rate evolution of binary grafting polymerization of butylmethacrylate and acrylic acid onto carboxymethylcellulose by ceric ion induced initiation studied by Sadeghi et al [33]. Sekhar et al, investigated chitosan and guar gum-g-acrylamide semi-interpenetrating microspheres (semi IPNMs) were prepared by water-in-oil emulsion cross-linking method using glutaraldehyde as a crosslinker. 5-fluorouracil (5-FU) is an anticancer drug was successfully loaded in these semi IPNMs. X-ray diffraction (XRD) and differential scanning calorimetric (DSC) examined the crystalline nature of drug after encapsulation into semi IPNMs. Scanning electron microscopy (SEM) reveals the formation of semi IPNMs is spherical with size around 200  $\mu\text{m}$ . The encapsulation efficiency of 5-FU was achieved up to 58%, in-vitro release studies were performed basic (pH 7.4) buffer medium [34]. Banyal et al, synthesized Grafting of binary mixtures of methyl methacrylate and some vinyl monomers onto mulberry silk fiber. Synthesis, characterization and preliminary investigations into gentian violet uptake by

graft copolymers by ceric ion induced initiation [35]. Dholakia et al, studied grafting of acrylonitrile (AN) onto sodium salt of partially carboxymethylated psyllium (Na-PCMPsy) have been carried out using a ceric ammonium nitrate (CAN) as a photoinitiator in an aqueous medium [36]. Pati et al, synthesized graft copolymerization of methyl methacrylate onto chitosan were investigated using ceric ammonium nitrate as the initiator. The effect of initiator concentration, monomer concentration, time and temperature on %G and %GE were studied [37]. Dincer et al, investigated the polymerization of acrylamide, initiated by a cerium (IV) ammonium nitrate-methionine redox initiator system was carried out in an aqueous solution at different reaction conditions [31]. Natural fibers have received vast attention because of their combustible, non-toxic, low cost, hydrophilic and biodegradable properties. In this study functionalization of cannabisindica fiber has been carried out by its grafting with acrylic acid (AAc) using Ce (+3)/ HNO<sub>3</sub> redox initiator couple in aqueous medium [39].

#### *Persulphate initiation*

Generally, ammonium persulphate, potassium persulphate or ferrous persulphate are used as initiators for graft polymerization. When an aqueous solution of persulphate is heated it decomposes to yield sulphate radical along with free radical species. The mechanism for grafting, postulated [40] as follows (Fig. 3):



**Fig. 3.** General reaction mechanism graft copolymerization by Persulphate Initiation

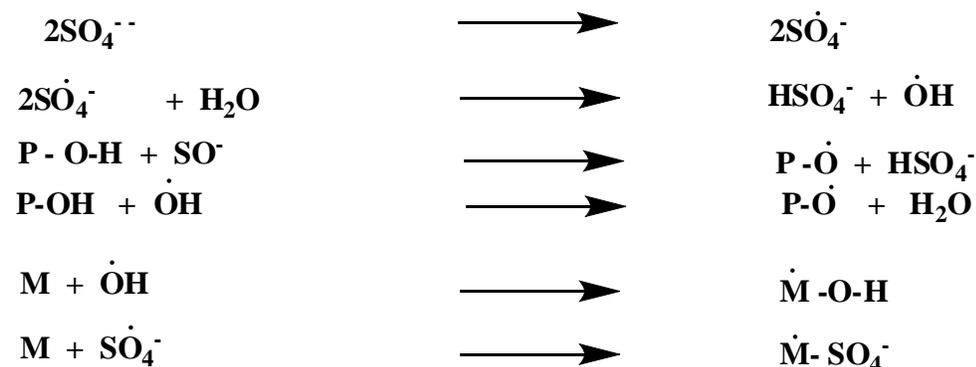
Where R-OH = polysaccharide, R Free radical species.

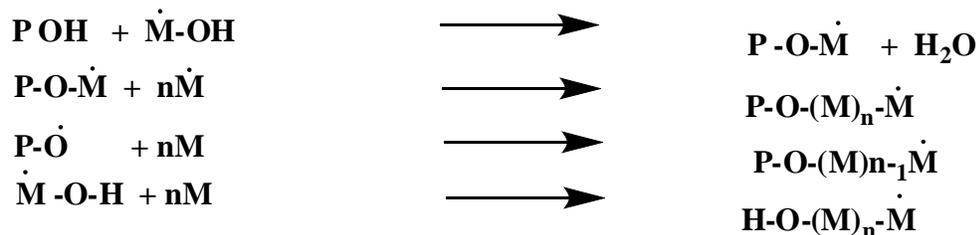
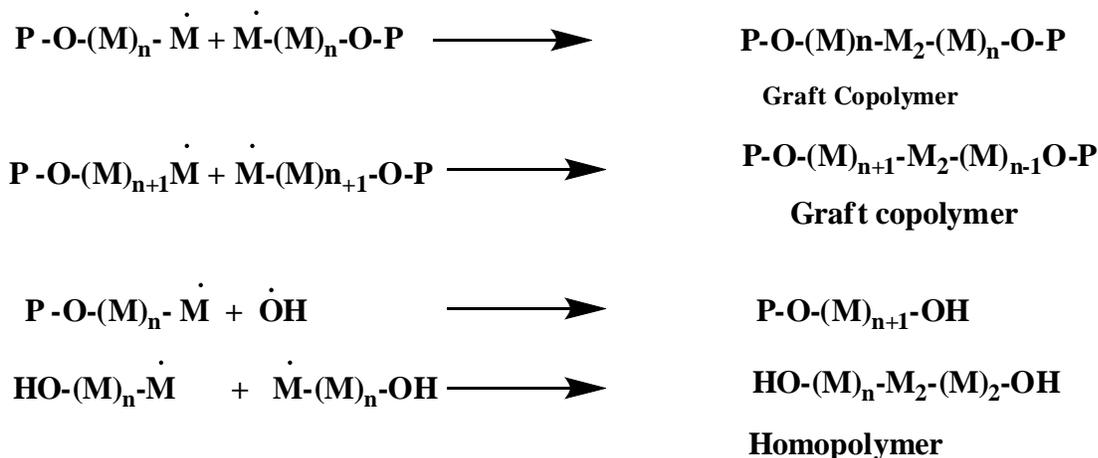
We are investigating from the literature that with an increase in the concentration of persulfate initiator, percentage grafting, and efficiency grafting initially increased, but with further increase in [persulfate initiator] beyond a certain limit, these grafting parameters

showed decreasing tendency. This behavior was explained by the fact that with the increase in [persulfate initiator] there is a concurrent increase in free radical formation which is able to attack polysaccharide chain of GG/its derivatives. This results in the formation of more macroradicals capable of grafting vinyl monomers on them. On further increasing the [persulfate initiator] above the threshold value equivalent to maximum grafting, a large number of free radicals are formed which may initiate homopolymerization of vinyl monomers at the expense of grafting.

Singh et al, synthesized psyllium and polyacrylamide based hydrogels for the use in drug delivery they had prepared psyllium and polyacrylamide based polymeric networks by using N,N-methylenebisacrylamide (N,N-MBAAm) as crosslinker [41]. Psyllium is a medicinally active natural polysaccharide, had been modified with polyacrylamide to develop the hydrogels, those can act as the potential candidate for novel drug delivery systems [42]. Kumar et al, studied psyllium and acrylic acid based polymeric networks were synthesized under different reaction conditions such as either air or inert conditions, and under the influence of  $\gamma$ -radiations using potassium persulphate (KPS) & hexamethylenetetramine (HMTA) as an initiator-crosslinker system [43]. Prashar et al, synthesized gum tragacanth-acrylic acid based hydrogels using KPS-ascorbic acid and glutaraldehyde as an initiator-crosslinker via free radical polymerization technique were also carried out [43]. Kaith et al, studied psyllium mucilage which was obtained from *Plantago Obata* had been modified through graft copolymerization and network formation using acrylic acid (AA) as the monomer, potassium persulphate (KPS) as an initiator and hexamethylenetetramine (HMTA) as cross-linker. The mechanism of this copolymerization reaction is shown in fig.4 [45].

### Initiation



**Propagation****Termination****Fig.4** – synthesis of Cross-linked Psy-g-poly(AA)

M = monomer free radical Psy-O\* = Backbone free radical (psyllium) [45].

Kaith et al, investigated psyllium had been functionalized with acrylamide in the presence of KPS/HMTA couple as an initiator-crosslinker system [45].

**Irradiation**

Nagger et al, reported hydrogels based on tara gum/acrylic acid (TG/AAc) were prepared by gamma irradiation, in the presence of N,N-methylene-bis-acrylamide(MBAAm) as a crosslinking agent [40]. Psyllium-N-vinylpyrrolidonebased hydrogels by radiation-inducedcrosslinkingalso reported. Polymers were characterized by SEM, FTIR and swelling studies. Swelling of the hydrogels was studied as a function of monomer concentration, total radiation dose, temperature, pH and salt is taken by the swelling medium [46]. Polymeric flocculent has been developed by graft copolymerization of acrylamide (AAm) with acrylic acid (AAc) using gamma irradiation technique. The grafted copolymer (PAAm/AAc) was characterized using Fourier-transform infrared spectroscopy (FTIR), and thermo-gravimetric analysis (TGA). The effects of reaction parameters such as total absorbed dose and monomer concentration on grafting yield were investigated [47].Iskandarsynthesized the graft copolymer

of methyl methacrylate onto starch and natural rubber latex was conducted by a simultaneous irradiation technique. Gamma rays from the cobalt-60 source were used as the initiator [48]. Shanmugapriya et al, studied graft copolymer of chitosan with acrylic acid polymer has been synthesized using ceric ammonium nitrate and nitric acid redox system under UV irradiation [49].

#### *FAS - H<sub>2</sub>O<sub>2</sub> as redox initiator*

Kalia et al, synthesized a medicinally important natural psyllium polymer was functionalized with acrylic acid using FAS-H<sub>2</sub>O<sub>2</sub> as a redox initiator and glutaraldehyde as a crosslinker [50].

#### *Microwave energy induced initiation*

The use of microwave energy has been used in the past two decades to improve the procedural limitation in the synthesis of a range of graft modified polysaccharide material. In fact, the increasing interest in green and clean environment-friendly chemistry has motivated the use of microwaves in the polysaccharide grafting modification. Microwave irradiation significantly reduced the use of toxic solvents, as well as the reaction time in mostly the grafting reaction of interest here, ensuring high yields product selectivity and cleans product formations. Furthermore, in many instances microwave synthesized polysaccharide copolymer reveal better properties for commercial exploitation than their conventionally synthesized counterparts [51]. In this way, the relatively higher yields and grafting efficiency could be achieved within a very short time with no or little addition of any radical initiators or catalyst, and the extent of grafting could be adjusted by controlling the microwave conditions [52-54] Microwave radiations cause “selective excitation” of the polar bonds only, which in turn leads to their rupture/cleavage. This cleavage of bonds creates many free radical sites on the polymer backbone. The “C-C” sequence of the backbone polymer remains unaltered by the microwave radiation since it is relatively nonpolar[55].

It depicts the graft polymerization mechanism initiated by individual microwave and based on free radical mechanism. Typically, the polar O-H bond can easily be broken under the action of microwave radiation, while the C-C bond (practically nonpolar) has not been affected. The cleavage of the O-H bonds leads to the formation of free radical “active” sites on the backbone of psyllium. These active sites can react with vinyl monomers to achieve the growth of chains, and the graft copolymer could be formed [56-57]

#### **Graft copolymerization of polysaccharides using different monomers**

Among various methods, graft copolymerization is the most attractive because it is a useful technique for modifying the chemical and physical properties of natural polymers. [58-59].

#### *Grafting by acrylic acid*

Psyllium and acrylic acid based polymeric networks under different reaction conditions such as in air, under the inert condition and under the influence of radiations using potassium persulphate (KPS)-hexamethylenetetramine (HMTA) as an initiator-crosslinker system [60]. Banyalet al reported that mulberry silk fiber was graft copolymerized with binary mixtures of acrylic acid, methyl acrylate and acrylonitrile with methyl methacrylate as the principal monomer in an aqueous medium by using CAN as a redox initiator. The binary vinyl monomers were graft copolymerized by using the grafting conditions like reaction time, temperature, the concentration of MMA and CAN as reported earlier in optimum percent grafting of MMA alone onto the same backbone. Graft copolymers were characterized by FTIR, SEM, swelling studies, moisture absorption and chemical resistance in the acidic and alkaline medium. Dye uptake (gentian violet) on graft copolymers were studied photo-calorimetrically at 420 nm. The dyeing capability of the graft copolymers with the binary mixture is more than the pure compound i.e. absorption capacity (dyeing capability) increased after the grafting [35]. Hydrogels based on tara gum/acrylic acid (TG/AAC) were prepared by gamma irradiation, in the presence of N,N-methylenebisacrylamide (MBAAM) as a crosslinking agent. The polymeric network formed were characterized by FTIR and evaluated by swelling studies as a function of MBAAM concentration, temperature, and nature of the swelling medium. The swelling kinetics of the hydrogels was studied in terms of the diffusion exponent. The results showed that the water diffusion into hydrogels is a non-Fickian type. Stress-strain curves of hydrogels were evaluated to calculate the shear modulus values and the average molecular weight between crosslinks. Moreover, the absorption under load at 37°C of water and urea aqueous TG/AAC hydrogels was determined [61]. Singh V. et al. 2010 studied, efficient mercury sorbent had been crafted by poly (acrylic acid) grafting onto *C. javanica* seed gum under microwave irradiation and synthesized graft copolymer samples with varying the reaction conditions of different % Grafting [62].

Natural polymers are industrially attractive because of their capability of removing the metal ions present in the waste water. Among the many other low-cost adsorbents identified chitosan had the highest sorption capacity for several metal ions. The use of sorbent chitosan makes it

possible to remove both heavy metals and organic compounds. Chitins, chitosan, grafting acrylic acid polymers are individually used for waste water treatment due to biocompatibility and low cost. Deshpande et al, has synthesized graft copolymers of chitosan with acrylic acid polymer had been synthesized using ceric ammonium nitrate, nitric acid redox system under UV irradiation [63].

Kumar et al. synthesized psyllium and acrylic acid based polymeric networks under different reaction conditions such as in air in avacuum and under the influence of  $\gamma$ -radiations using potassium persulphate (KPS) hexamethylenetetramine (HMTA) as an initiator-crosslinker system. Initially, optimization of various reaction parameters was performed under all the different reaction conditions. It had been observed that the percent grafting varies with varying reaction conditions with maximum grafting (61.15%) reported in the case of synthesis carried out in vacuum followed by the synthesis in air (61.00%) and then in the case of synthesis under the influence of  $\gamma$  radiations [64]. Graft copolymerization of butylmethacrylate (BMC) and acrylic acid (AA) onto carboxymethylcellulose (CMC) was carried out under argon atmosphere in a homogeneous aqueous medium by using ceric ammonium nitrate (CAN) as an initiator [30].

Kaith et al., observed psyllium mucilage which was obtained from *Plantago ovata* have been modified through graft copolymerization and network formation using acrylic acid (AA) as the monomer, potassium persulphate (KPS) as an initiator, and hexamethylenetetramine (HMTA) as a cross-linker [65].

#### *Grafting by acrylo-nitrile*

The copolymer of *Plantago psyllium* mucilage and acrylonitrile had been synthesized in the presence of nitrogen using ceric ion/nitric acid redox couple. Polyacrylonitrile grafted Psyllium (PSY-g-PAN) was characterized by IR spectroscopy and tested for its flocculation efficiency in the textile effluent by the standard jar test method. The efficiency of removal of solid waste from textile effluents depends on various parameters viz. adsorbent dose, temperature, pH, contact time, RPM etc [66]. Photoinduced grafting of acrylonitrile (AN) onto sodium salt of partially carboxymethylated psyllium (Na-PCMPsy) had been carried out using ceric ammonium nitrate (CAN) as a photoinitiator in an aqueous medium. The reaction variables including concentrations of initiator, nitric acid, monomer and amount of the backbone as well as time and temperature have been varied for establishing grafting. The influence of these reaction conditions on the grafting yield had been discussed. The FTIR spectra, thermal analysis (TGA)

and scanning electron microscopic (SEM) techniques had been used for the characterization of graft copolymer [36]. Plantago psyllium mucilage (PSY), an anionic natural polysaccharide consisting of pentosan and uronic acid obtained from the seeds of Plantago psyllium (*Plantago family*), was grafted with acrylonitrile (AN). Graft copolymers were prepared by ceric ion initiated solution polymerization technique and were characterized by FT-IR spectroscopy, scanning electron microscopy and differential scanning calorimetric [66]. Photo-induced grafting of acrylonitrile (AN) onto sodium salt of partially carboxymethylated psyllium (Na-PCMPsy) carried out using ceric ammonium nitrate (CAN) as photoinitiator in an aqueous medium. The reaction variables including concentrations of initiator, nitric acid, monomer and amount of the backbone as well as time and temperature had been varied for establishing grafting [67]. V. et al. 2006, prepared the graft copolymer of Cassia siamea with acrylonitrile under microwave (MW) irradiation without adding any radical initiator or catalyst. Free radicals are generated here due to the dielectric heating caused by the localized rotation of the hydroxyl groups at the polysaccharide backbone and initiate grafting. Graft copolymerization did by following reaction mechanism and observed that microwave promoted grafting over the conventional grafting, %G and %E for both the methods were compared [68]. Vandna et al. 2003 prepared the grafting of polyacrylonitrile (PAN) onto guar gum in water, without using any radical initiator or catalyst within a very short reaction time through the microwave (MW) irradiation [69].

Ikhuria et al, studied on the graft copolymerization of acrylonitrile onto cassava starch by ceric ion induced initiation the graft copolymerization. Ten grades of graft copolymers were synthesized five by varying the initial concentration of the monomer and the other five by varying the initial concentration of the initiator. Evidence of graft copolymerization of the hydrolyzed products was obtained from the air analyses. Some grafting parameters such as % grafting ratio and % conversion were favored by an initial increase in the monomer concentration. However, these parameters were observed to decrease at much higher concentrations (>3 M). Evidence of hydrolysis shows that the grafted copolymers could be used as flocculants [32]. Singh V et al 2007, have synthesized Starch-g-poly(acrylonitrile) Using a very low concentration of potassium persulfate as an initiator, acrylamide could be efficiently grafted onto starch under microwave irradiation and for the grafting O<sub>2</sub> removal from the reaction vessel was not required [70].

Mishra et al, synthesized acrylonitrile grafted Plantago psyllium in the presence of nitrogen using ceric ion-nitric acid redox system. The effects of polymer dose, pH and contact time on the

removal of solid waste from textile effluent are reported. The optimum dose was found to be 1.6 mg/L, at which a maximum solid removal of 94% suspended solid (SS) and 80% total dissolved solid (TDS) was seen. The most suitable pH was acidic (pH 4.0) and neutral (pH 7.0), for SS and TDS removal, respectively. The optimum treatment duration was one hour. X-ray analysis of PSY-g- PAN and solid waste from effluent before and after treatment suggests the interaction of the solid waste with the PSY-g-PAN copolymer [11]. Singh et al, reported, graft copolymerization of acrylonitrile (AN) onto saccharumcilliarefibre has been carried out in the presence of potassium persulphate and ferrous ammonium sulphate (FAS-KPS) as redox initiator in an autoclave. Various reaction parameters such as pressure, time, pH, concentrations of initiator and monomer were optimized to get maximum graft yield (35-59%). Grafted and ungrafted saccharincilliarefibres were then subjected to evaluation of some of their properties like swelling behavior in different solvents, moisture absorbance under different humidity levels, water uptake and resistance towards chemicals such as hydrochloric acid and sodium hydroxide. The characterization of the graft copolymers was carried out by FTIR spectrophotometer, X-ray diffraction (XRD) and scanning electron microscopic (SEM) studies [71]. Polyacrylonitrile grafted agar/ sodium alginate had been synthesized in an aqueous medium under reflux condition in the presence of potassium persulfate as a free radical initiator [72].

#### *Grafting by acrylamide*

Most coal preparations are carried out in water medium and moisture and water content is problematic in handling and specific energy value. A novel polymeric flocculants had been developed by graft copolymerization of acrylamide (AAm) with acrylic acid (AA) using  $\gamma$  irradiation technique [49]. Saifuddin and Yusumira observed that polymers had been molecularly imprinted for the purpose of binding specifically to  $\alpha$ -tocotrienol (vitamin E). A molecularly imprinted polymer (MIP) material was prepared using  $\alpha$ -tocotrienol as the imprinted molecule, acrylamide as functional monomer and macroporous chitosan beads as a functional matrix. Chitosan-graft-polyacrylamide was synthesized without any radical initiator or catalyst using microwave (MW) irradiation [73]. Ahuja et al. 2009 have synthesized Xanthan-g-poly(acrylamide) under the microwave radiation. Xanthan-g-poly(acrylamide) was prepared to employ microwave-assisted grafting and ceric-induced grafting. Microwave assisted grafting of acrylamide on xanthan gum was done using the method reported earlier [74].

Hossein Hosseinzadeh reported the effect of different reaction conditions on the grafting of acrylamide (AM) onto k-carrageenan (kC) using potassium persulfate (KPS) initiator had been studied by determining the grafting parameters. The reactions were carried out under argon atmosphere in a homogenous aqueous medium; the graft copolymer was characterized by FTIR spectroscopy. It was observed that with increasing AM, kC, and KPS concentrations, as well as reaction time and temperature the grafting parameters, were also increased, but further increase of reaction conditions disfavored these parameters [75]. Vandna et al. 2005. Synthesized Chitosan-graft-polyacrylamide (Ch-g-PAM) without any radical initiator or catalyst using microwave (MW) irradiation. Under optimal grafting conditions, 169% grafting was observed at 80% MW power in 1.16 min [76]. Polyacrylamide grafted cellulose had also been demonstrated to be a very efficient and selective sorbent for removal of mercuric ions from synthetic aqueous solutions. The mercury-uptake capacity of the graft polymer is as high as 3.55 mmol/g and sorption is also reasonably prompt. Thus, 0.2 g of the graft copolymer is able to extract 50 ppm Hg(II) from 50 ml water completely in less than ten minutes. The Hg (II) sorption is selective and no interferences have been observed in the presence of Ni (II), Co (II), Cd(II), Fe(III), Zn(II) ions in 0.1 M concentrations at pH 6. Regeneration of the loaded polymer without losing its original activity can be achieved using hot acetic acid. The graft copolymer described seems very suitable for removal of large amounts of mercury in hydrometallurgical applications and may also be useful for other water treatments [77]. Pal et al. 2010 synthesized the polyacrylamide-grafted sodium alginate, through microwave radiation and investigated the effect of reaction parameters (i.e., irradiation time and monomer concentration) onto the percentage grafting. Microwave irradiation was used to generate the free-radical sites on the polysaccharide backbone [77].

Singh V et al. 2006, have synthesized Potato Starch-g-poly(acrylamide) Using a very low concentration of potassium persulfate as an initiator, acrylamide could be efficiently grafted onto potato starch under microwave irradiation and for the grafting O<sub>2</sub> removal from the reaction vessel was not required [79].

#### *Polymer methylmethacrylate grafting.*

UV-radiation induced grafting of methylmethacrylate onto sodium salt of partially carboxymethylated psyllium had been carried out using ceric ammonium nitrate as a photoinitiator in an aqueous medium. The reaction variables including concentrations of initiator,

nitric acid, monomer and amount of the backbone as well as time and temperature have been varied for establishing the optimized reaction conditions for grafting. Sadeghi et al, reported drafted poly methyl methacrylate (PMMA) onto Carboxymethyl cellulose (CMC) backbone in a homogeneous solution using ceric ammonium nitrate (CAN) as an initiator and water as a solvent. The structure of virgin CMC sample and grafted with monomers was characterized by FTIR spectra and TGA analysis. The thermal properties of pure CMC and grafted with monomers were evaluated with a simultaneous thermal analysis system. The results showed that the thermal stability of grafted samples was appreciably improved. The effects of various reaction conditions such as monomer, polysaccharide, initiator concentration and reaction temperature on the percentage of conversion, graft yield (G %) and graft efficiency (GE %) were investigated [30].

The graft copolymerization of methyl methacrylate onto starch and natural rubber latex was conducted by a simultaneous irradiation technique to obtain the degradable plastic  $\gamma$ -rays from cobalt-60 source was used as the initiator. The grafted copolymer of starch-polymethyl methacrylate and the grafted copolymer of natural rubber-polymethyl methacrylate were mixed in the blender and dried it in the oven. The dried grafted copolymer mixture was then molded using hydraulic press machine. The effect of irradiation dose, composition of the grafted copolymer mixture, film forming condition and recycle effect was evaluated. The parameters observed were tensile strength, gel fraction and soil burial degradability of grafted copolymer mixture. It was found that the tensile strength of grafted copolymer mixture increased by  $\gamma$ -ray irradiation. Increasing of the grafted copolymer of natural rubber-polymethyl methacrylate content, the gel fraction and tensile strength of the grafted copolymer mixture increased by Iskandar [48]. The graft copolymerization of methyl methacrylate onto chitosan was investigated using ceric ammonium nitrate as the initiator. The effect of initiator concentration, monomer concentration, time and temperature on %G and %GE were studied. The antibacterial activity of chitosan, as well as the grafted samples, was investigated using some gram positive and gram negative bacteria. Grafted products improved considerably the antibacterial activity [39]. The UV-radiation induced grafting of methyl methacrylate onto sodium salt of partially carboxymethylated psyllium carried out using ceric ammonium nitrate as a photoinitiator in an aqueous medium. The reaction variables, including concentrations of initiator, nitric acid, monomer, and the amount of the backbone as well as time and temperature had been varied for establishing the optimized reaction conditions for grafting. The influence of these reaction

conditions on the grafting yields had been discussed [80]. Babu and Dhamodharan reported that polymethylmethacrylate (PMMA) in the brush form is grown from the surface of magnetite nanoparticles by ambient temperature atom transfer radical polymerization (ATATRP) using a phosphonic acid based initiator. The surface initiator was prepared by the reaction of ethylene glycol with 2-bromoisobutyl bromide, followed by the reaction with phosphorus oxychloride and hydrolysis. This initiative is anchored to magnetite nanoparticles via physisorption. The ATATRP of methyl methacrylate was carried out in the presence of CuBr/PMDETA complex, without a sacrificial initiator, and the grafting density was found to be as high as 0.90 molecules/nm<sup>2</sup>. The organic-inorganic hybrid material thus prepared shows exceptional stability in organic solvents, unlike unfunctionalized magnetite nanoparticles which tend to flocculate. The polymer brushes of various number average molecular weights were prepared and the molecular weight was determined using size exclusion chromatography, after degrading the polymer from the magnetite core [81].

### **Applications grafted copolymer**

#### *In pharmaceutical field*

A wide variety of grafted natural polysaccharides had been used to fabricate different types of drug delivery system. Natural polysaccharides and their derivatives were used to controlled release of drug in the pharmaceutical and biomedical field. The advantages of the controlled drug delivery system are mainly the achievement of an optimum concentration, usually for prolonged times, the enhancement of the activity of labile drugs due to their protection against hostile environments and the diminishing of side effects due to the reduction of high initial blood concentration [4]. The antibacterial activity of chitosan, as well as the grafted samples, was investigated using some gram positive and gram negative bacteria. Grafted products improved considerably the antibacterial activity [36]. Physiological substances play very important role in food due to their ability to deactivate free radicals in organisms. Free radicals may be a danger to cells and their components if their level of concentration was not controlled. In such a case, cancer, and other severe diseases may occur. The control of the radicals is realized via the activity of antioxidants like Vitamins A, C or E which may donate electrons to the radicals. Vitamin E is one of the most important lipid-soluble primary defense antioxidants. Vitamin E is a potent antioxidant that protects the body against oxidative damage, notably cell membranes and cholesterol transporting lipoproteins [102]. Singh

et al., also reported that the tetracycline hydrochloride drug was released from the modified psyllium with polymethacrylate polymeric networks by using N,N-MBAAm as a crosslinker and ammonium persulfate (APS) as an initiator which used in colon-specific drug delivery. The release of water-soluble drug tetracycline hydrochloride entrapped in hydrogels occurs only after water penetrates the polymeric networks to swell and dissolve the drug followed by diffusion along the aqueous pathways to the surface of the device. The effect of pH on the release pattern of tetracycline was studied in varying the pH of the release medium. However, the amount of drug release in pH 7.4 buffer solutions was higher than the pH 2.2 buffer and distilled water [103].

### Conclusion

Graft copolymerization is a distinctive method among different techniques for modifying natural polymers mostly for polysaccharides. Graft copolymerization is an effective method to incorporate useful properties to the main polymer backbone, and these are useful in many applications in different fields. Grafting of the synthetic polymer is an easy method to add new properties to a natural polymer with minimum loss of the initial properties of the substrate. Grafted copolymer plays a vital role in changing its physical-chemical properties. Graft copolymerization is an efficient means to incorporate the desired feature into polysaccharide. Grafted polysaccharide also more stable than its virgin counterpart. In the present review, we are reporting the syntheses, characterizations, and applications of polysaccharide grafted/crosslinked copolymers from the above it can be concluded that the polysaccharide grafted/crosslinked copolymer is an efficient and novel technique and have wide areas of the application such as in drug delivery, adsorption, treatment of textile/tannery, domestic/sewage waste water and also in agriculture and serving for mankind.

### Reference

1. Singh, R.P.; Pal, S.; Krinamurti, S.; Adnard, P.; Akber, S. K. *Pure. Appli. Chem.* **2009** 81, 525. doi:10.1351/PAC-CON-08-08-17
2. Chintan Bhavsar, Munira Momin, Sankalp Gharat & Abdelwahab Omri, *Expert Opinion on Drug Delivery*, 2017, Pages 1-16, doi.org/10.1080/17425247.2017.1241230
3. Kumar D, Chandra R, Dubey R. J. *Technological Advances and Scientific Res.* 2016; 2(4): 185-189, doi: 10.14260/jtasr/2016/34
4. Maiti, S.; Ranjit, S.; Sa, B. *Int. J. Pharm. Res.* **2010** 2, 1350.

5. You, Q.; Yin, X.; Zhang,S.; Jiang, Z.; *Carbohydr.Polym.***2014**, 99, 1,doi.org/10.1016/j.carbpol.2013.07.088
6. Singha, A. S.; Kaith, B. S.; Chauhan, A.; Misra, B.N. *J. Polym. Mater.* **2006** 23, 3456.
7. Kumara, A.; Srivastavaa, A.; Yu, I., Bo, G., *Matt. Prog. Polym. Sci.***2007**, 32, 1205. doi:10.1016/j.seppur.2008.07.016
8. Chauhan, G. S.; Bhatt, S. S.; Kaur, I.; Singha, A. S.; Kaith, B. S. *J. Polym. Degrad. & Stab.***2000**, 69, 261. doi:10.1016/S0141-3910(00)00063-X
9. Rudzinski, W.E.; Dave, A. M.; Vaishnav, U. H.; Kumbar, S. G.; Kulkarni A. R. &Aminabhavi T. M.; *Design. Mon. Polym.*, **2002**, 5, 39. doi:10.116339/156855502760151580
10. Kumar,P.; Ganure, A. L.; Subudhi, B. B.; Shukla, S. *Int. J. Pharma. Pharma. Sci.* **2004**, 6, 975. doi: 10.1007/s13346-015-0221-7.
11. Mishra, A.; Agarwal, M.; Bajpai, M.; Rajani, S.; Mishra, R.P. *Iran. Polym. J.***2002**, 11, 381.
12. Mishra, A.; Srinivasan, R.; Bajpai, M.; Dubey, R. *Coll. Poly. Sci.***2004**, 282, 722. doi.org/10.1007/s00396-003-1003-1
13. Deepak kumar<sup>2</sup>, Nida khan<sup>1</sup>, Pramendra Kumar<sup>1</sup>, Jyoti Pandey<sup>2</sup> *Green Chemistry & Technology Letters* 3, 2016,151-159, doi: 10.18510/gctl.2016.235
14. Julie Meimoun, Vincent Wiatz, Ren Saint-Loup, JulienParcq, Audrey Favrelle , Fanny Bonnet and Philippe Zinck *Starch/Stärke* 2017, 69, 1-23,doi: 10.1002/star.201600351
15. Sen, G.; Mishra, S.; Rani, S, G.U.; Rani, Prasad, R. *Int. J. Biol.Macromol.* **2012**, 50, 369. doi: 10.1016/j.ijbiomac.2011.12.014.
16. B. Xu, G. Gu, C. Feng, X. Jiang, J. Hu, G. Lu, S. Zhang and X. Huang, *Polym. Chem.*, 2016, 613–624, doi: 10.1039/C5PY01644D
17. S. Lin, A. Das and P. Theato, *Polym. Chem.* 1-11, 2017, doi: 10.1039/C6PY01996J.
18. Mishra, S.; Sinha, S.; Dey, K. P.; Sen, G. *Carbohydr. Polym.* **2014**, 99, 462. doi:10.1016/j.carbpol.2013.08.047
19. Tung, N. T.; Khoi, N. V. *J. Appl. Chem.***2010**, 48, 621. doi:10.1016/j.carbpol.2014.08.052
20. Tripathy, T.; Singh, R. P. *High. Perf.,Eur. Polym. J.* **2000**, 36, 1471. doi: 10.1016/S0014-3057(99)00201-3

21. Tripathy, T.; Singh, R. P. Performa. *Eur. Polym. J.* **2000**, 36, 1491. doi:10.1016/j.polymer.2000.09.012
22. Sen, G.; Mishra, S.; Sinha, S.; Dey, K.P, *Carbohydr. Polym.* **2014**, 99, 462. doi:10.1016/j.carbpol.2013.08.047
23. Mishra, A., Srinivasan, R., Gupta, R. *Colloids. Poly. Sci.* **2004**, 281, 187. doi:10.1007/s00396-002-0777-x
24. Dholakia, A.; Jivani, J.; Patel, K.H.; Trivedi, H.C. *Der. Chem. Sinica.* **2011**, 2, 80. doi:10.1080/19443994.2014.905978
25. Kumar, K.; Mittal, H. *J. Appl. Polym. Sci.* **2012**, 123, 1874. doi: 10.1002/app.34675
26. Singh, B.; Chauhan, G.S.; Kumar, S.; Chauhan, N. *Carbohydr. Polym.* **2007**, 67, 190. doi:10.1016/j.carbpol.2006.05.006
27. Nayak, B.R.; Singh R.P.; *J. Appl. Polym. Sci.* **2001**, 81, 1776. doi: 10.1002/app.1610
28. Bhatia, M.; Ahuja, M. *Schol. Res. Lib Der. Pharma. Lett.* **2014**, 62; 127. doi:10.1080/17458080.2013.822108
29. Xie, W.; Zu, P.; Wang, W.; Liu, Q. *Carbohydr. Polym.* **2000**, 50, 35. doi:10.1016/S0144-8617(01)00370-8. 30
30. Sadeghi, M.; Soleimani, F.; Yarahmad, M.; *Cpden. Ojcheg.* **2011**, 27, 1033.
31. Chauhan, A.; Kaith, B.; *J ChemEng Process Technol*, **2013** S6: 002. doi:10.4172/21577048.S6-002
32. Ikhuria, E. U.; Folayan, A. S.; Okieimen, F. E. *Int. J. Biot. Mole. Bi. Res.* **2011**, 1, 10. Article Number - A86C3C940373
33. Sadeghi, M.; Soleimani, F.; Yarahmadi, M. *J. Appl. Chem.* **2011**, 27, 967
34. Sekhar, E. C.; Krishna, K.S.V.; Rao, R.; Raju, R. *J. Appl. Pharm. Sci.* **2011**, 01, 199. doi:10.1155/2014/583612
35. Banyal, S. K.; Kaith, B. S.; Sharma, R. K. *Adv. Appl. Sci. Res.* **2011**, 2, 193.
36. Dholakia, A.; Patel, K. H.; Trivedi, H. C. *Der, Chem. Sin.* **2011**, 2, 106.
37. Pati, M. K.; Nayak, P. L. *Int. J. Res. Pharm. Chem.* **2011**, 1, 1.
38. Mishra, A.; Rajani, S.; Dubey, R. *Macromol. Mater. Eng.* **2002**, 287, 592. doi:10.1002/1439-2054(20020901)287
39. Singha, A. S.; Rana, A. K. *Iran. Polym. J.* **2011**, 20, 913. , doi: 10.1002/app.35256

40. Xie, W.; Xu, P.; Wang, W.; Liu, Q. *Carbohydr. Polym.* **2002**, 50, 35.  
doi:10.1016/S0144-8617(01)00370-8
41. Singh, B.; Chauhan, G.S.; Kumar, S.; Chauhan, N. *Carbohydr. Polym.* **2007**, 67; 559.  
doi:10.1016/j.carbpol.2006.05.006
42. Singh, B.; Chauhan, G.S.; Sharma, D.K.; Chauhan, N. *Carbohydr. Polym.* **2007**, 67, 559.  
doi: 10.1016/j.carbpol.2006.06.030.
43. Kumar, K.; Kaith, B. S.; Mittal, H. *J. Appl. Polym. Sci.* **2012**, 3, 123.  
doi:10.1002/app.34675
44. Prashar, D.; Kaith, B.S.; Kalia, S.; Sharma, S. *Int. J. Pharm. Pharm. Sci.* **2012**, 4, 16.
45. Kaith, B. S.; Kumar, K. *press. Polym. Lett.* **2007**, 7, 474.  
doi:10.3144/expresspolymlett.2007.66
46. El-Naggar, S. G. A. Alla, M. Sen, *Carbohydr. Polym.* 89 (2012) 478.  
doi:10.1016/j.carbpol.2012.03.031
47. M. Khalek, A. W. M.; Mahmoud, G. Australia. *Bas. Appl. Sci.* **2011**, 5, 271. ISSN  
19918178
48. S.Iskandar, *Atom Indonesia* Vol. 37 (2011) 1 24.
49. Shanmugapriya, A.; Ramammurthy, R.; Munusamy, Y.; Parapurath, S. *J. Water Resour. Prote.* **2011**, 3, 380. doi:10.4236/jwarp.2011.36048
50. Kaila, S.; Kumari, A.; Kaith, B.S.; Singha, A.S. *Adv. Matt.* **2010**, 1,  
123. doi:10.5185/amlett.2010.6129
51. Singh, V.; Kumar, P.; Sanghi, R.; *prog. Polym. Sci.* **2012**, 37,  
340. doi:10.1016/j.progpolymsci.2011.07.005
52. Joshi, J.M.; Sinha, V.K. *Carbohydr. Polym.* **2007**, 67,  
427. doi:10.1016/j.carbpol.2006.06.021
53. Singha, A.; Rana, A. *Iran. Polym. J.* **2011**, 20, 913.
54. Singh, V.; Tiwari, A.; Shukla, P.K.; Singh, S.P.; Sanghi, R.; *React. Funct. Polym.* **2006**,  
66, 1306. doi:10.1016/j.reactfunctpolym.2006.03.013
55. Kumar, K.; Kaith, B.S.; Mittal, H.; *J. Appl. Polym. Sci.* **2012**, 123,  
1874. doi:10.1002/app.34675
56. Gabriel, C.; Gabriel, S.; Grant, .EH.; Halstead, B.S.J.; Mingos, D.M.P. *Chem. Soc. Rev.*  
**1998**, 27, 213.

57. Stuerger, D.; Gaillard, P. *J. Tetrahedron* **1996**, 52, 5505.
58. Chemat, D. Z., Hamada, B.; Chemat, F. *Molecules* **2007**, 12, 1399. doi:10.3390/12071399
59. Sen, G.; Mishra, S.; Sinha, S. Dey, K.P. *Carbohydr. Polym.* 99 (2014) 462. doi.org/10.1016/j.carbpol.2013.08.047
60. Mishra, S.; Sen, G. *Int. J. Bio. Macromole.*, **2011** 48, 688.
61. Mishra, S.; Sen, G.; Rani, U.; Sinha, S. *J. Bio Macromole*, 2011,49, 591. doi:10.1016/j.ijbiomac.2011.06.015.
62. Singh, V., Singh, S.K. and Maurya, S., *Chemical Engineering Journal* 160, no. 1 (2010): 129-137.
63. Deshpande, M.V. *J. Sci. Indus. Res.* **1986**, **45**, 277.
64. Kumar, K.; Verma, M. *J. Appl. Polym. Sci.* **2007**, 103, 1025. doi: 10.1002/app.25293
65. Kaith, B.S.; Kumar, K. *Iran. Polym. J.* **2007**, 16, 529.
66. Mishra, A.; Rajani, S.; Agarwal, M.; Dubey, R., *J. Polym. Bull.* **2002**, 48, 439. doi:10.1007/s00289-002-0056-5
67. Mishra, A.; Shrinivasan, R.; Gupta, R. *Colloids. Polym. Sci*, **2003**, 282 187. doi: 10.1007/s00396-002-0777-x
68. Singh, V.; Tripathi, D.N. *J. Appl. Polym. Sci.* **2006** 101, 2384. doi 10.1002/app.23878
69. Singh, V.; Tripathi, D.N.; Tiwari, A.; Sanghi, R.; *J. Appl. Polym. Sci.* **2004**, 92, 1569. doi10.1002/app.21245
70. Singh, V.; Tiwari, A.; Pandey, S.; Singh, S.K. *eXPRESS Polym. Lett.* **2007**, 1, 51. doi:10.3144/expresspolymlett.2007.10
71. Singh, R.; Pal, S.; Krishnamoorthy, S.; Adhikary, P.; Ali, A. *Pure. Appl. Chem.* **2009**, 81, 525.
72. Chhatbar, M.; Meena, R.; Prasad, K.; Siddhanta, A. *Indian J. Chem.* **2009**, 48, 1085.
73. Saifuddin, N.; Yusumira, A. *Eurp. J. Chem.* **2010**, 7, 1362.
74. Ahuja, M.; Singh, K.; Kumar, A.; *Carbohydr. Polym.* **2009**, 76 261. doi:10.1016/j.carbpol.2008.10.014
75. Hosseinzadeh, H. *Iran. Polym. Sci.* **2009**, 2, 1.
76. Singh, V.; Tripathi, D.N.; Tiwari, A.; Sanghi, R. *Polym.* **2006**, 47, 254. doi:10.1016/j.polymer.2005.10.101

77. Sherrington, D.C.; Bicap, N. F.; Senkel, B. *React. Funct. Polym.* **1999**, 41, 69.PII:S1381-5148(99)00021-8
78. Pal, S.; Singh, R.P.; Sen, G.; *J. Appl. Polym. Sci.* **2010**, 115, 63.)doi 10.1002/app.30596
79. Singh, V.; Tiwari, A.; Pandey, S.; Singh, S.K. *Starch/Stärke* **2006** , **58**.536 doi10.1002/star.200600520
80. Dholakia, A., Javani, J.; Trivedi, J.; Patel, K.; Trivedi, H. *Inc. J. Appl. Polym. Sci.* **2011**, 5, 42.
81. Babu, K.; Dhamodharan, R.; *Nanoscale. Res. Lett.* **2008**, 23, 109.doi10.1007/s11671008-9121-9
82. Agnihotri, S. A.; Aminabhavi, T. M. *International Journal of Pharmaceutics* **2006**, 324 (2), 103-115 DOI: <https://doi.org/10.1016/j.ijpharm.2006.05.061>.
83. Kolya, H.; Pal, S.; Pandey, A.; Tripathy, T. *European Polymer Journal* **2015**, 66, 139-148 DOI: <https://doi.org/10.1016/j.eurpolymj.2015.01.035>.
84. Guo, P.; Anderson, J. D.; Bozell, J. J.; Zivanovic, S. *Carbohydrate Polymers* **2016**, 140, 171-180 DOI: <https://doi.org/10.1016/j.carbpol.2015.12.015>.
85. Kim, S.; Requejo, K. I.; Nakamatsu, J.; Gonzales, K. N.; Torres, F. G.; Cavaco-Paulo, A. *Process Biochemistry*, DOI: <https://doi.org/10.1016/j.procbio.2016.12.002>.
86. Abbasian, M.; Jaymand, M.; Niroomand, P.; Farnoudian-Habibi, A.; Karaj-Abad, S. G. *International Journal of Biological Macromolecules* **2017**, 95, 393-403 DOI: <https://doi.org/10.1016/j.ijbiomac.2016.11.075>.
87. Lalita; Singh, A. P.; Sharma, R. K. *International Journal of Biological Macromolecules* **2017**, 99, 409-426 DOI: <https://doi.org/10.1016/j.ijbiomac.2017.02.091>.
88. Singh, B.; Chauhan, N.; Kumar, S.; Bala, R. *International Journal of Pharmaceutics* **2008**, 352 (1–2), 74-80 DOI: <https://doi.org/10.1016/j.ijpharm.2007.10.019>.
89. Singh, B.; Sharma, N.; Chauhan, N. *Carbohydrate Polymers* **2007**, 69 (4), 631-643 DOI: <https://doi.org/10.1016/j.carbpol.2007.01.020>.
90. 9. Sharma, R. K.; Lalita. *Carbohydrate Polymers* **2011**, 83 (4), 1929-1936 DOI: <https://doi.org/10.1016/j.carbpol.2010.10.068>.
91. 10. Shahid, M.; Bukhari, S. A.; Gul, Y.; Munir, H.; Anjum, F.; Zuber, M.; Jamil, T.; Zia, K. M. *International Journal of Biological Macromolecules* **2013**, 62, 172-179 DOI: <https://doi.org/10.1016/j.ijbiomac.2013.08.018>.

92. Soppimath, K. S.; Kulkarni, A. R.; Aminabhavi, T. M. *Journal of Controlled Release* **2001**, 75 (3), 331-345 DOI: [https://doi.org/10.1016/S0168-3659\(01\)00404-7](https://doi.org/10.1016/S0168-3659(01)00404-7).
93. El-Sheikh, M. A. *Carbohydrate Polymers* **2016**, 152, 105-118 DOI: <https://doi.org/10.1016/j.carbpol.2016.06.088>.
94. Huang, M.; Liu, Z.; Li, A.; Yang, H. *Journal of Environmental Management* **2017**, 196, 63-71 DOI: <https://doi.org/10.1016/j.jenvman.2017.02.078>.
95. Hu, Y.; Tang, M. *Carbohydrate Polymers* **2015**, 118, 79-82 DOI: <https://doi.org/10.1016/j.carbpol.2014.11.011>.
96. Mittal, H.; Jindal, R.; Kaith, B. S.; Maity, A.; Ray, S. S. *Carbohydrate Polymers* **2015**, 115, 617-628 DOI: <https://doi.org/10.1016/j.carbpol.2014.09.026>.
97. Rani, P.; Sen, G.; Mishra, S.; Jha, U. *Carbohydrate Polymers* **2012**, 89 (1), 275-281 DOI: <https://doi.org/10.1016/j.carbpol.2012.03.009>.
98. Fosso-Kankeu, E.; Mittal, H.; Mishra, S. B.; Mishra, A. K.. *Journal of Industrial and Engineering Chemistry* **2015**, 22, 171-178 doi: <https://doi.org/10.1016/j.jiec.2014.07.007>.
99. Sand, A.; Vyas, A.; Gupta, A. K. *International Journal of Biological Macromolecules* **2016**, 90, 37-43 doi: <https://doi.org/10.1016/j.ijbiomac.2015.11.085>.
100. Liu, Y.; Sun, Y.; Sun, L.; Rizwan ur, R.; Wang, Y. *Journal of Functional Foods* **2016**, 24, 429-437 DOI: <https://doi.org/10.1016/j.jff.2016.03.034>.
101. Li, B.; Shen, J.; Wang, L. *Int. Res. J. Public Environ Health* **2017**, 2,30-35. [doi.org/10.15739/irjpeh.17.00](https://doi.org/10.15739/irjpeh.17.00)
102. Koroskenyi, B.; McCarthy, S.P.; *J. Polym. Envir.* **2002**, 10, 222. doi15662543/02/07000093/0
103. Singh, R.P.; Tripathy, T.; Karmakar, G.P.; Rath, S.K.; Karmakar, N.C.; Pandey, S.R.; Kanna, K.; Jain, S.K.; Lan, N.T. *Current. Sci.* **2000**, 78, 789. doi: 10.1002/pen.11138