

Chapter 3

**CARRAGEENAN BASED HYDROGELS AND
COMPOSITES: A SYSTEMATIC INVESTIGATION
REPORTING THEIR MULTIDIMENSIONAL ESSENCE**

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ABSTRACT

Carrageenans are red seaweed extracted sulfated linear polysaccharides which possess excellent gel forming properties. They are extensively used for their thickening, gel forming as well as stabilizing properties in food industries. Due to their good protein binding abilities, they are preferred in meat and dairy preservation. Structurally, they are polymers of alternately repeating disaccharide unit, α -(133)-D-galactose and β -(134)-3,6-anhydro-D- or L-galactose. Sulphation of the galactose gives them the distinguishing properties. Three isomeric forms of carrageenan with slightly different properties exist in nature. Their hydrogels are used in tissue engineering and controlled drug delivery while their composites find applications in wound dressings, protection of fish and meat from dehydration. In the field of medicine, carrageenans possess anticoagulant, antithrombotic, antiviral, and antitumor activities. Besides they also possess many industrial applications.

Keywords: carrageenans, red seaweed, sulphation, tissue engineering, hydrogels

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1. INTRODUCTION

Carrageenan stands for a generic name of a family of water-soluble, sulphated polysaccharides present in the cell walls of members of the Gigartinales and used extensively as gels and thickeners in the food industry (Pereira and Mesquita 2004; De Ruiter and Rudolph 1997). Its structure is related to agar though they have a high sulfate content. Their main chain consists of alternating co-polymers of 1,4- α - and 1,3-Beta-D-galactopyranose and 3,6-anhydro-D-galactopyranose (Bartkowiak and Hunkeler 2001). The backbone is based on a repeating disaccharide sequence of P-D-galactopyranose (Viebke et al. 1995). In the food industry, it is the third most significant hydrocolloid, after gelatin (animal origin) and starch. The commercial used Carrageenans are extracted from *Kappaphycus alvarezii* and *Eucheuma denticulatum* (Pereira et al. 2009). Over the past several decades, like others biopolymers, carrageenans also has received increased attention for their applications in chemical, biomedical, and food industries.

2. STRUCTURE AND TYPES

Carrageenan consist of copolymers, α -(133)-D-galactose and β -(134)-3,6-anhydro-D- or L-galactose in alternating fashion. The difference in the position and number of sulfate residues in the repeating unit gives rise to different isomeric forms of carrageenan. A Greek prefix is usually added viz κ , λ and ι to distinguish the isoforms (Zablackis and Santos 1986). All isomeric forms bear negative charges with 1, 2, and 2.7 per disaccharide unit of galactose in κ , ι and λ respectively. A substantial amount of commercially important carrageenan is present in cell walls of red sea weeds (Wong and Craigie 1978). The presence of sulfated polysaccharides (galactans) in carrageenans imparts them a special property of forming the gel in water thereby making it amenable to be used in pharmaceutical, cosmetic and food industries (Jadeja and Tewari 2009). The carrageenophytes pertaining to the Petrocelidaceae, Gigartinaceae, Phyllophoraceae and Cystocloniaceae families (Gigartinales, Rhodophyta) are extensively distributed in the Atlantic center and north coast of Portugal and Indian sea (Jadeja and Tewari 2009; Pereira and Mesquita 2003).

2.1. Kappa Carrageenan

The κ -carrageenan occur in Gigartinaceae and Petrocelidaceae gametophytes (Villanueva and Montaño, 2003). K-Carrageenan is composed of carbohydrate chains of α -(1,3)-linked units of carrabiose, forming a linear, alternating sequence of D-galactose-4- sulphate and 3,6-anhydro-D-galactose units (Thomson and Fowler, 1981) (Figure 1). The gametophytic plants produce a κ/ι -hybrid type of carrageenan; these are also known as “weak-gelling κ -carrageenan”, or “kappa-2.” Kappa-2 type of carrageenan range from almost pure ι -carrageenan to almost pure κ -carrageenan, and consists of mixed polysaccharide chains containing both κ - and ι -units (Campo, Kawano, da Silva, and Carvalho, 2009)

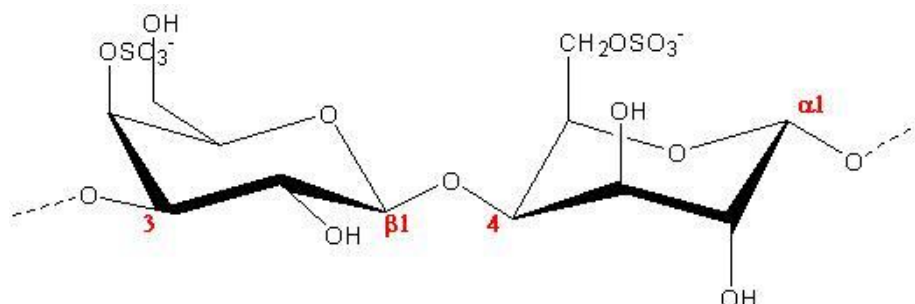


Figure. 1. Chemical structure of κ -carrageenan.

Sources http://polysac3db.cermav.cnrs.fr/discover_carrageenans.html.

2.2. Iota Carrageenan

Iota-Carrageenan is produced mainly by species of the genus *Eucheuma* (*Eucheuma denticulatum*) and also by some other species of the Phylloporaceae and Cystocloniaceae families (Villanueva and Montaño, 2003). The structure of Iota carrageenan is similar like κ -carrageenan with an additional half sulphate ester residue (Thomson and Fowler, 1981) (Figure 2).

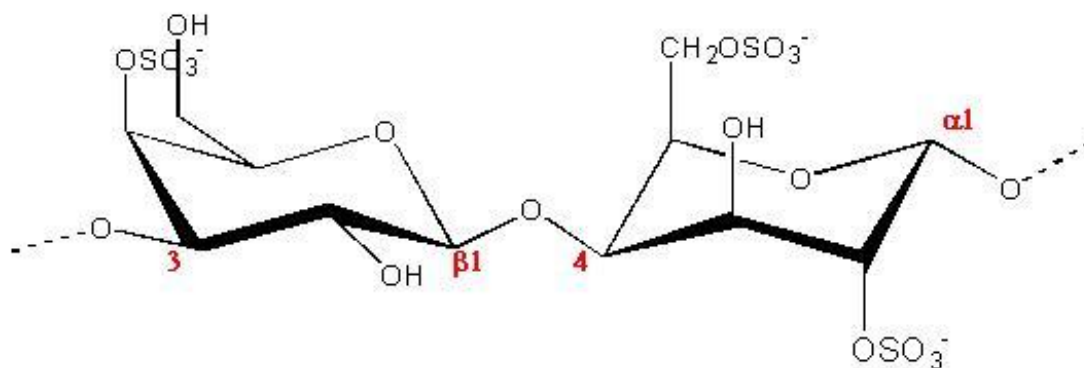


Figure. 2. Chemical structure of Iota-carrageenan.

Source: http://polysac3db.cermav.cnrs.fr/discover_carrageenans.html.

2.3. Lambda Carrageenan

λ -Carrageenan is obtained from different species of the *Gigartina* and *Chondrus* genera. The sporophytic plants of these seaweeds produce λ -carrageenan (McCandless, West, and Guiry, 1983). λ Carrageenan appears habitually in the tetra-sporophytic stages (Villanueva and Montaño, 2003). λ -carrageenan is of varying composition but consists almost equal proportions of 1,3 linked and 1,4 linked D-galactose units. X-ray diffraction studies have shown that these molecules have a double helical conformation with covalent inter-chain bonds, forming both a secondary and tertiary structure making carrageenan resistant to enzymatic degradation (Thomson and Fowler, 1981). (Figure 3).

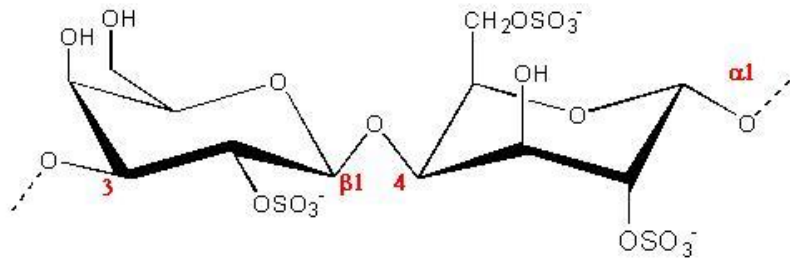


Figure 3. Chemical structure of Lambda-carrageenan.

Source: http://polysac3db.cermav.cnrs.fr/discover_carrageenans.html.

3. CARRAGEENAN-BASED HYDROGELS

Because of their exceptional properties, carrageenans are generally used as ingredients in a variety of applications. They have numerous major characteristics that make them very useful in many food and non-food applications. They are used as cost-effective stabilizers, thermo-reversible gelling agents, binders, thickeners, texture modifiers, drug delivery and moisture retainers. Since carrageenan is a highly negatively charged polysaccharide, it can interact with species carrying a positive charge. Many reports are published in this regard, such as the interaction of carrageenan with univalent and divalent cations with gelatin and with chitosan. Another feature is its ability to swell intensely in aqueous media thereby forming hydrogels. These hydrophilic swellable materials (hydrogels) are defined as polymeric materials with the ability to absorb $> 20\text{w/w}$ in water and still maintain a distinct three-dimensional structure. Superabsorbents are hydrogels with very high swelling capacity ($>1,000\text{ w/w}$). Superabsorbent hydrogels of carrageenan have wide applications in hygienics, food, pharmaceuticals, cosmetics, and agriculture. One method for the synthesis of low cost superabsorbent hydrogels is to graft copolymerize vinylic monomers onto polysaccharides. Acrylonitrile, acrylic acid, etc. have been successfully grafted onto polysaccharides such as starch, cellulose and their derivatives (Hosseinzadeh et al., 2005; Takemasa, Chiba, and Date, 2002; Theerkeelsen, 1993) (Usov, 1998).

Using film immersion in a solution of glutaraldehyde followed by 110°C high-temperature curing for two and twenty-five minutes respectively, a hydrogel prepared from carrageenan of *Kappaphycus alvarezii* showed higher swelling capability as well as pH sensitivity when compared to the commonly used method of preparation. This method is claimed to be simple and rapid (Distantina and Fahrurrozi 2013). In tissue engineering, the engineered constructs require vascularization which poses a major limitation in such applications. K- Carrageenan-based hydrogel beads possess the property of efficiently encapsulating the platelet-derived growth factor and its sustained release in tissue engineering. This method is suggested to improve the vasculature in such experiments and can be effectively utilized in bone tissue engineering (Santo et al. 2009). γ ray produced hydrogels from carrageenan and Poly(N-vinyl-2-pyrrolidone) possess excellent wound dressing utility. The hydrogel has transparent nature that makes it possible to analyze the healing visually. Besides, it is elastic, more fluid absorbing and mechanically more strong than usual dressing materials (Sen at al 2005). In a one-step approach, from carrageenan and sodium alginate, a superabsorbing hydrogel was prepared which is biocompatible and sensitive to pH and claimed to be good drug delivering system (Hosseinzadeh 2012).

4. CARRAGEENAN BASED COMPOSITES

Carrageenan consist of copolymers, α -(133)-D-galactose and β -(134)-3, 6-anhydro-D- or L-galactose in alternating fashion. The difference in the position and number of sulfate residues in the repeating unit gives rise to different isomeric forms of carrageenan viz κ λ and ι carrageenan (Zablackis and Santos 1986). All isomeric forms bear negative charges with 1, 2, and 2.7 per disaccharide unit of galactose in κ , ι and λ respectively. From the κ and ι carrageenan gel powders, excellent films can be prepared. Regulating the properties of the of the biopolymer films especially the tensile strength, water vapor permeability and elasticity is essential for bio-application of these materials. Using different acid systems, the chitosan/ κ carrageenan composite film exhibited different properties which could widen their window of use. Malic acid dissolved chitosan and κ carrageenan in 2% ascorbic acid yield composite films having enhanced tensile strength and elongation percentage while lactic acid enhances the water vapor permeability of the film. Citric acid does not have any substantial impact on any of these properties (Park et al. 2001). Composite films made up of carrageenan and polyethylene oxide proved to have good mucoadhesion property in wound dressing which is required for enhanced adherence with the tissue. The films are transparent, elastic and have a smooth texture. Further, the films loaded with streptomycin and diplofenac showed the controlled release of these antibiotics up to 72 hours thereby forming the high inhibition zones for different bacteria around the wound. These films loaded with streptomycin are suitable for preventing infection in chronic wounds while as for relieving pain and inflammation, diplofenac loaded films may be used (Boateng et al. 2013). Edible films are the coating or packaging materials that form an integral part of the food. Such films are eaten along with the food. These films form barriers that prevent the moisture, gasses, etc. from surrounding the food or through different phases of a food item to prolong the shelf life of food materials (Karbowaik et al. 2006). Carrageenan-based edible films have already been in use to prevent dehydration of meat, fish, and poultry (Shaw et al. 1980); dry foods capsules sausage casings, etc. (Karbowaik et al. 2006). Superior tensile strength, enhanced thermal stability, and better dispersion qualities were imparted to composite biofilms of carrageenan reinforced with kenaf fiber derived cellulose nanocrystal (Zarina et al. 2014). Low-efficiency solar cells can be prepared from the blend of κ carrageenan and poly(3, 4-ethylenedioxythiophene) after incorporation into the electrolyte system of dye-sensitized solar cells (Ng and Camacho 2015). Nanocomposites based on carrageenan hydrogels containing laponite RD clay showed improved swelling characteristic than nanocomposite with no carrageenan. Further such nanocomposites exhibit enhanced crystal violet dye adsorption from water which increases with increase in clay content. The carrageenan content has a negative impact on the cationic dye adsorption (Mahdavinia et al. 2012).

5. ANTICOAGULANT AND ANTITHROMBOTIC ACTIVITY

Carrageenan is classified into different types that consist of 22–35% sulphate groups. The anticoagulant activity of carrageenan is confirmed by many reports. λ -carrageenan has about twice the activity of unfractionated carrageenan and four times the activity of κ -carrageenan. The most active carrageenan has almost one fifteenth the activity as compared to heparin. The

anticoagulant activity of carrageenan is due to its anti-thrombic property. λ -Carrageenan showed greater anti-thrombic activity than κ -carrageenan probably due to its higher sulphate content, whereas the activity of the unfractionated material is somewhere between the two. λ -Carrageenan consistently delayed the clotting time and was more toxic than κ -carrageenan. The difference in anticoagulation activity and toxicity is not due to the difference in sulphate content between two carrageenan (Shanmugam and Mody, 2000). Amidolytic studies initially indicated that the anti-thrombin activity might be mediated via AT-III (anti-thrombin-III), the major mechanism followed by heparin. Carrageenans show the restricted activity of amidolysis of thrombin via AT-III that cause Xa amidolysis. These interactions may be influenced by biochemical structure and side chains of polymers, i.e., sulphation, size, pattern of ionic substitution and polymer rigidity (G Kindness, Long, and Williamson, 1979). However, successive studies using AT-III-depleted plasma showed residual anti-thrombin activity in the presence of carrageenans. λ -Carrageenan promoted the inactivation of thrombin by 'anti-thrombin BM'. These observations would, therefore, entail that there is either anti-thrombin activation via heparin co-factor II (HC-II) and/or a direct anti-thrombin effect (G Kindness, Long, and Williamson, 1980; Wunderwald, Schrenk, and Port, 1982).

6. ANTIVIRAL ACTIVITY

Carrageenan is an inhibitor of several enveloped viruses, including human pathogens like human immunodeficiency virus, herpes simplex virus (HSV), human cytomegalovirus, human rhinoviruses and others (Cáceres, Carlucci, Damonte, Matsuhira, and Zúñiga, 2000; M. Carlucci, Scolaro, and Damonte, 1999; Girond, Crance, Van Cuyck-Gandre, Renaudet, and Deloince, 1991; Marchetti et al., 1995; Stiles, Guptill-Yoran, Moore, and Pogranichniy, 2008). Carrageenan acts by inhibiting the binding or the entry of virions into cells (Buck et al., 2006; Grassauer et al., 2008). This finding is supported by heparin sulfate which is similar to carrageenan and which acts as an HPV cell-attachment factor. Papillomavirus infectivity is mitigated *in vitro* by carrageenan. It also possesses antiviral activity against sexually transmitted HPV types that can cause cervical cancer and genital warts. *In vitro* studies show that carrageenan works against other viruses, including herpes simplex viruses and some strains of HIV-1. This observation is also supported by murine model systems (Baba, Snoeck, Pauwels, and De Clercq, 1988; Gonzalez, Alarcon, and Carrasco, 1987; Lynch et al., 1994; Witvrouw and De Clercq, 1997; Zeitlin, Whaley, Hegarty, Moench, and Cone, 1997). However, carrageenan possesses thousand fold higher inhibition activity for Herpes simplex virus and HIV-I than for genital HPVs. Carlucci *et al.* (1997, 2004) reported that the λ -carrageenan has potent antiviral effect against HSV-I and HSV-2. (M. Carlucci, Scolaro, Nosedá, Cerezo, and Damonte, 2004; M. J. Carlucci et al., 1997).

Zacharopoulos and Phillips (1997) described the ability of carrageenan solutions (*lambda*, *kappa*, or *iota*) to prevent HSV-2 infection. Using a commercially available nasal spray containing *iota*-carrageenan, Leibbrandt *et al.* (2010) tested its effect on influenza A virus in mouse models. After a lethal dose of H1/N1, the ameliorative effect of carrageenan was found similar to the drug, oseltamivir. Thus, *iota*-carrageenan-containing nasal sprays can be recommended as an alternative treatment for influenza virus for neuraminidase inhibitor drugs. The safety and efficacy of *iota*-carrageenan nasal sprays in patients with

common cold symptoms are established (Eccles et al., 2010). Nasal sprays appear to be a promising treatment for safe and effective treatment of early symptoms of the common cold.

7. ANTI-TUMOUR AND IMMUNOMODULATORY ACTIVITIES

Several studies have identified that carrageenans have antiproliferative activity in cancer cell lines invitro, as well as inhibitory activity of tumor growth in mice (de Souza et al., 2007; Yuan and Song, 2005; Yuan, Song, Li, Li, and Dai, 2006; Zhou, Sheng, Yao, and Wang, 2006). Carrageenan also shows anti-metastatic activity by blocking the interactions between cancer cells and the basement membrane thereby inhibiting tumor cell proliferation and tumor cell adhesion to various substrates. The oral administration of several seaweeds can cause a major decrease in the occurrence of carcinogenesis in vivo (Yamamoto, Maruyama, Takahashi, and Komiyama, 1986). Further, carrageenan possesses the anti-colon cancer activity in male rats (Hagiwara et al. 2001). Histopathological examination did not demonstrate any enhancement of carcinogenesis by carrageenan. Carrageenan does not possess any cancer-promoting activity at the highest dietary level of 5.0% for colorectal carcinogenesis under the present experimental conditions (Hagiwara et al., 2001).

8. OTHER BIOLOGICAL ACTIVITIES

All carrageenans possess antioxidant activity. λ -Carrageenan revealed the highest antioxidant and free radical scavenging activity. There occurs a positive correlation between sulfate content and antioxidant activity (de Souza et al., 2007). Carrageenan from red marine algae is reported as a major inflammatory agent in rodents and mice leucocytes to produce tumor necrosis factor- α . Moreover, some types of carrageenans promote specific macrophage activation, while some carrageenans appear to inhibit macrophage functions (Wijesekara, Pangestuti, and Kim, 2011). The feeding of 344 Fischer rats on diets containing 15% *kappa/lambda*-carrageenan from *G. radula* resulted in a cholesterol-lowering effect (Reddy, Watanabe, and Sheinfil, 1980). The addition of carrageenan into the diet reduce the blood cholesterol level (PanlasiguiPhD, Baello, DimatangalBSc, and DumelodMSc, 2003).

9. INDUSTRIAL USES OF CARRAGEENAN

Carrageenan is used in various industries like food industry (Desserts, ice creams, milkshakes, yogurt, salad dressings, sweeteners, condensed milk), sauces (used to increase viscosity), beer (clarifiers to remove haze causing proteins), pates and processed meat (substitute for fat, increase water retention and increase volume or improve slice ability), toothpaste (stabilizer to prevent constituents separating), fruit gushers (ingredient in encapsulated gel), fire fighting foam (thickeners to cause foam to become highly sticky), shampoo and cosmetic creams (thickeners), air fresheners gel, shoe polish (gel to increase viscosity), diet sodas (to enhance texture and suspend flavours), pet food, personal lubricants, vegetarian hot dogs, etc.

Carrageenan is a suitable support material for the immobilization of whole cells, as proven by several applications in different industrial processes. The approval of carrageenan as a food-grade additive and the simplicity of the immobilization protocol have stimulated its application in the food industries. The processes of immobilization of whole cells using carrageenan allows its application in production processes for pharmaceutical compounds and fine chemicals (van de Velde, Lourenço, Pinheiro, and Bakker, 2002).

Industrial vinegar production is a biochemical process which uses bacteria for the fermentation process. K-Carrageenan gel beads act as carriers for the continuous production of acetic acid (OSUGA, MORI, and KATO, 1984). In recent studies, a successful continuous production of vinegar was reported using a bubble mixed tabletop bioreactor with κ -carrageenan-immobilized *Acetobacter suboxydans* cells (Tosa and Shibatani, 1995). Fermented milk products can be extracted from skimmed milk by inoculating immobilized bacterial cultures. Three different strains of *Lactococcus lactis* and one strain of *Leuconostoc mesenteroides* were separately immobilized in κ -carrageenan/locust bean gum gel and used in a 2-L stirred reactor (I. Sodini, C.-Y. Boquien, G. Corrieu, and C. Lacroix, 1997). K-Carrageenan beads synthesized by a static mixer process were used to immobilize the yeast culture cells for beer production (Mensour, Margaritis, Briens, Pilkington, and Russell, 1996). Using a fluidized bed fermenter, it is reported that cells of *Zymomonas mobilis* immobilized in k-carrageenan can be used for ethanol production from glucose. This technique was also used to study the production of ethanol from starch (Krishnan, Nghiem, and Davison, 1999).

Streptomyces aureofaciens immobilized in κ -carrageenan is used for the production of tetracycline and chlortetracycline, instead of conventional fermentation (Teruel, Gontier, Bienaime, Saucedo, and Barbotin, 1997). Semi-synthetic antibiotics are prepared by coupling of a β -lactam core with the side chain, such as phenylacetic acid, d-phenyl glycine, or d-*p*-hydroxyphenyl glycine. 6-Aminopenicillanic acid (6-APA) is prepared by the fermentation process of penicillin G using the enzymatic hydrolysis. For 6-APA production, k-carrageenan is used as a medium with *E. coli* cells having penicillin-amidase activity (Nagalakshmi and Pai, 1997). These immobilized cells can be repeatedly used up to 20 cycles with the efficiency of 60-90% of the initial penicillin-amidase activity. Some d-amino acids have been recognized as important intermediates in drug production. d-Aspartic acid can be used for the production of synthetic penicillins (Takamatsu and Tosa, 1992). When d/l-aspartic acid is used as a substrate for the l-aspartate β -decarboxylase of *P. dacunhae* cells, l-aspartic acid is converted to l-alanine but d-aspartic acid remains unchanged because of high stereospecificity of the biocatalyst. So, d-aspartic acid and l-alanine can be produced at the same time using *P. dacunhae* cells immobilized in carrageenan (Takamatsu and Tosa, 1992). d/l-Aspartic acid is chemically synthesized from fumaric acid and ammonia. D-Aspartic acid is crystallized from the reactor effluent by acidification process and recovered by centrifugation. To the resulting liquor by the addition of ammonia, l-Alanine is also recovered by centrifugation after crystallization followed by concentration and cooling. Since 1988, this system has been industrialized for the continuous production of d-aspartic acid and l-alanine using *P. dacunhae* cells immobilized in κ -carrageenan. For the first time in 1973, industrial application of immobilized whole cells was developed with the use of κ -carrageenan gels for the preparation of l-aspartic acid (Tanabe Seiyaku, Japan). The industrial production of some other compounds (l-malic acid, l-alanine, l-tryptophan, 1,5-dimethyl-2-piperidone) for use in food and medical applications is based on the same principles.

The co-immobilisation of *Nitrosomonas europaea* and *Pseudomonas* sp. in κ -carrageenan is used for nitrogen removal that use the oxygen gradient inside the entrapment beads (V. A. dos Santos, Tramper, and Wijffels, 1996; V. M. dos Santos, Bruijnse, Tramper, and Wijffels, 1996). The immobilization of *M. aurum* in κ -carrageenan and its use in an air-bubble fermenter resulted in an improvement of its morpholine-degrading capacity (Poupin, Mazure, and Truffaut, 1996; Swain, Waterhouse, Venables, Calley, and Lowe, 1991). The carrageenan gel and immobilized microbial cell method was used for degradation of 4-chlorophenol (Wang, Li, Shi, Qian, and Zhou, 1997). K-Carrageenan/gelatin gel beads have also been co-immobilised into aerobic and anaerobic microbial communities (Gardin and Paus, 2001). Under air-limited conditions, these immobilisates catalyze the degradation of 2,4,6-trichlorophenol. Pentachlorophenol pesticide degradation in contaminated soil was attempted with the use of UG30 *Pseudomonas* sp. immobilized in κ -carrageenan (Cassidy, Shaw, Lee, and Trevors, 1997).

10. OTHER USES OF CARRAGEENAN

Kappa carrageenan is used in very small quantity to prevent separation of whey from cheese, ice creams to control texture and ice crystal growth. It is used in chocolate milk to keep cocoa suspended in milk. Stability of carrageenan can be improved by mixing it with water or milk. Lambda or mixtures of carrageenan are used to improve liquid coffee whiteners by preventing the separation of fat. Carrageenan has emulsifying, stabilizing, colloid or gum property so can be used in food industry for wide applications. Many food products that we use in our daily life have added carrageenan for their uniform texture. These products are not prepared, packaged and stored for long periods of time without carrageenan. Carrageenan is utilized as a thickener and suspension medium for gel formation, so it is used as an emulsifying agent. Carrageenan is mainly used in dairy industry. It has the unique ability to suspend cocoa in chocolate milk at very low concentrations (ca. 300 ppm). A very fragile milk gel structure is supposed to hold the cocoa in suspension that is not even identified by even pouring of milk. Different concentration of carrageenan is required for visible and practical stabilization of cocoa. *Iota*-carrageenans which have textures very similar to those of gelatin gels are used in dessert gel preparation. *Iota*-carrageenan has a higher melting temperature. So it can be replaced with gelatin in the food industry. Food items prepared with carrageenan does not require refrigerator in tropical climate conditions. These food items prepared with carrageenan are not soft in texture, so do not easily melt in the mouth like gelatin products. However, *iota* based gels can retain their tender structure even after a long time whereas gelatin tends to toughen. *Kappa* carrageenan or furcellaran have fragile gel structure, so these are not suitable for the dessert preparation. This problem can be mitigated by the addition of locust bean galactomannan into the *k*-carrageenan, and *kappa*-locust bean or *iota*- *kappa*-locust bean blends are also used for this purpose. Locust bean gum is also used to purify the *k*-carrageenan during filtration. This purified carrageenan gum is used by several industrial manufacturers. In toothpaste, carrageenans are utilized as a “binder” to introduce the required rheological properties to the paste, and it also provide the cosmetic quality of “sheen.” One another comparatively much cheaper gum i.e., carboxymethyl cellulose is also used in U.S. domestic market but still there is high demand

for carrageenan products in various industrial products. Outside the United States carrageenan has maintained a strong position for its immunity to prevent degradation of enzymes which affects the cellulose gum. Gelatin is extracted from pig skin, tendon and bones, so carrageenan forms the product of choice for vegetarians. In contrast to emulsifiers and normal carrageenans, when *iota*-carrageenan is combined with sodium stearyl lactylate, the synergistic effect imparts highest stabilizing/emulsifying capacity even under hot and cold conditions. In the context of its safety, all the authorities worldwide agree with the safety of carrageenan. However, Tobacman (2001a) and Tobacman et al. (2001b) give contrasting views regarding its biosafety. (J. Tobacman, Wallace, and Zimmerman, 2001; J. K. Tobacman, 2001).

CONCLUSION

In red seaweeds, carrageenans have an analogous function to cellulose of higher plants. They are sulfated and possess negative charge. Sulfation is responsible for their reactivity. They are available for consumption in the form sodium, potassium or calcium salts. They possess negligible toxicity and are suitable and recommended for use in food, dairy and other industries.

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