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To cite this article: Bhawna Bisht , U. C. Lohani , Vinod Kumar , Prateek Gururani & Rajat Sinhmar (2020): Edible hydrocolloids as sustainable substitute for non-biodegradable materials, Critical Reviews in Food Science and Nutrition, DOI: [10.1080/10408398.2020.1827219](https://doi.org/10.1080/10408398.2020.1827219)

To link to this article: <https://doi.org/10.1080/10408398.2020.1827219>



Published online: 09 Oct 2020.



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REVIEW

## Edible hydrocolloids as sustainable substitute for non-biodegradable materials

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### ABSTRACT

Edible hydrocolloid polymers have created significant deliberation in modern eons due to their numerous advantages of being used as edible materials over synthetic materials, which could be helpful to the food industry as well as toward environmental sustainability. In the current scenario, where biopolymers have replaced petroleum-based materials, natural edible hydrocolloids are now in demand to combat the harmful impacts of non-biodegradable materials. This review addresses the importance of natural edible hydrocolloids, materials that can be used to form hydrocolloid gel, their properties, synergistic interactions of hydrocolloids and various applications in food and biomedical fields,

### KEYWORDS

Biodegradable; hydrocolloid; polymer; sustainability; synergistic

## Introduction

India has a tremendous effect on the ecosystem and human health with growing urbanization and massive accumulation of non-biodegradable materials over the past decades. At present, around 150 million tons of non-biodegradable materials such as plastic have been produced annually the world, and production and use continues to grow (Shit and Shah 2014). Plastics also have become an integral part of daily life which have become a major threat to the environment, leading to 25% of the total volume of land pollution (Modebelu and Isiuw 2014). Most plastics are crude oil based undegraded polymer which causes serious environmental pollution that remain in the landfills for years (Maheshwari et al. 2013). On the other hand, only an insignificant amount of the generated waste is utilized while the rest is discarded/under-utilized (Suresh and Kumar 2012) which fail to meet the increasing demands of social sustainability and environment safety.

Excessive disposal of petroleum-based non-biodegradable materials has triggered greater attention and hence the hunt for natural solutions has led to production of advanced materials such as biodegradable material using biopolymers (Kanmani and Rhim 2014). Waste valorization is an alluring concept, which in many countries has now gained popularity due to the rapid increase in waste residues. Therefore, researchers are not only developing valorization strategies but also concentrating on creating greener materials using green technologies (Arancon et al. 2013). The demand for ecologically sustainable materials is growing to tackle numerous challenges such as sustainability, biodegradability, environmental issues, economics, and biocompatibility.

Effective valorization of biodegradable materials plays an important role in preserving a clean environment in order to substitute non-biodegradable materials and enhances economic value through the utilization of biodegradable materials to either promote a range of economically viable biomolecules or turn them into value-added products that serve as an alternative waste treatment for the disposal and efficient management of waste (Suresh and Chandrasekaran 1998; Chang, Chen, and Jao 2007; Bhaskar et al. 2010).

Keeping in mind the growing concern on the ecosystem and human health nowadays the goal of the present solution is to implement various strategies and methods to maximize the reuse of biodegradable materials and to reduce environment stress, efficiently and stably.

In recent years, dropping the use of synthetic materials has become a pro-ecological tendency in order for a cleaner, safer and greener future. The replacement of non-biodegradable materials by biodegradable materials is one of the problem-solving strategies that seems to be a good alternative to the non-biodegradable materials (Shit and Shah 2014). The generation of biodegradable materials or bio-wastes residues obtained from the food processing industry is extremely diverse due to the wider use of horticulturally grown crops, a broad array of processes and multiplicity of the product (Joshi, Kumar, and Kumar 2012), which is a major worldwide concern along the entire food value chain i.e., from production to consumption (Godfray et al. 2010).

These generated bio-wastes are high in moisture content, rich in organic compounds and poor biological stability, therefore most susceptible to enzymatic degradation and rapid auto-oxidation, resulting in putrefaction (Rabetafika et al. 2014). The long term disposal of these bio-wastes not

only results in greenhouse gas emissions during decomposition (Dhillon et al. 2011), but also facilitates a breeding ground for bacteria, pets and mice leading to plague spread, and thus adversely affecting the environment as well as human health due to improper disposal system without viable application (Hegazy and Ibrahium 2012; Marshall and Farahbakhsh 2013; Cheok et al. 2018). Moreover, the additional impact of the bio-wastes disposal cost is affecting the country's economy (Baiano 2014).

Utilization of biodegradable bio-wastes as the raw material with some remarkable natural hydrocolloids derived from plants, animals, microbes and seaweeds for the development of edible and biodegradable materials could be an effective way in overcoming several issues such as improving processing efficiency, increasing profitability, and exploring "Taste over waste" that helps in achieving overall sustainability. Sustainable and edible materials from diverse natural resources have been considered as valuable alternative to non-biodegradable petroleum-based plastic materials due to its enormous abundance, renewable, cost-effective, environmentally friendly, as well as biodegradable and biocompatible properties (Sorrentino et al., 2007; Tang et al. 2012), thereby providing safer and attractiveness and applicability in the pharmaceutical, agricultural, and environmental fields. By providing environmentally benign products and achieving "zero waste economy." The search for low-cost, environmentally friendly materials has led to the development of different biodegradable plastics incorporating natural edible hydrocolloid. This has led to a drive, by the agroindustry, for waste reduction and upgrading techniques to reduce costs and achieve new sources of income.

The substitution of traditional recycling methods by edible and biodegradable polymers should be regarded and motivated researchers to synthesize new polymers that can after practice be returned to the biological cycle. Development of edible and biodegradable such as plates, glasses, cups, utensils, fillers and cutleries from biodegradable materials are a trending way to overcome these problems. Edible and biodegradable materials can be used as utensils for serving or eating semi-solids foods that can be consumed safely or can be used in food packaging. These are environment-friendly because animals can easily recycle or eat them.

Currently, edible hydrocolloids based biodegradable materials have gained significant interest toward as an alternative to the synthetic non-biodegradable materials due to its beneficial characteristic, as it can be consumed like the food itself and its biodegradability.

This review therefore highlights a sustainable and biodegradable replacement, which would act as a key functional leap forward toward zero plastic consumption and wastage. This paper focuses mainly on the existing and potential future sources of hydrocolloids in the food industry and provides new insights into the properties, merits, demerits, uses and applications of natural edible hydrocolloids in the food industry, which shape future sources, establish technological and health advantages.

## Edible hydrocolloids in foods

The word "hydrocolloid" is a Greek word that comprises of two words i.e., "Hydro" means "water" and kolla means "glue" (Wustenberg 2015), which generally defines diverse groups of heterogeneous long chain bio-polymers that form viscous colloidal dispersions and/or liquid gel (Milani and Maleki 2012; Razavi 2019). Polysaccharides and proteins are a range of hydrocolloids which are extensively used by modifying the solution physical properties to perform various functions in a number of industrial sectors (Phillips and Williams 2009).

The existence of many hydroxyl groups increases their affinity to bind water producing hydrophilic dispersion, exhibiting colloidal properties which is intermediate between a true solution and a suspension. They are thus congruously termed as "hydrocolloids" (Saha and Bhattacharya 2010).

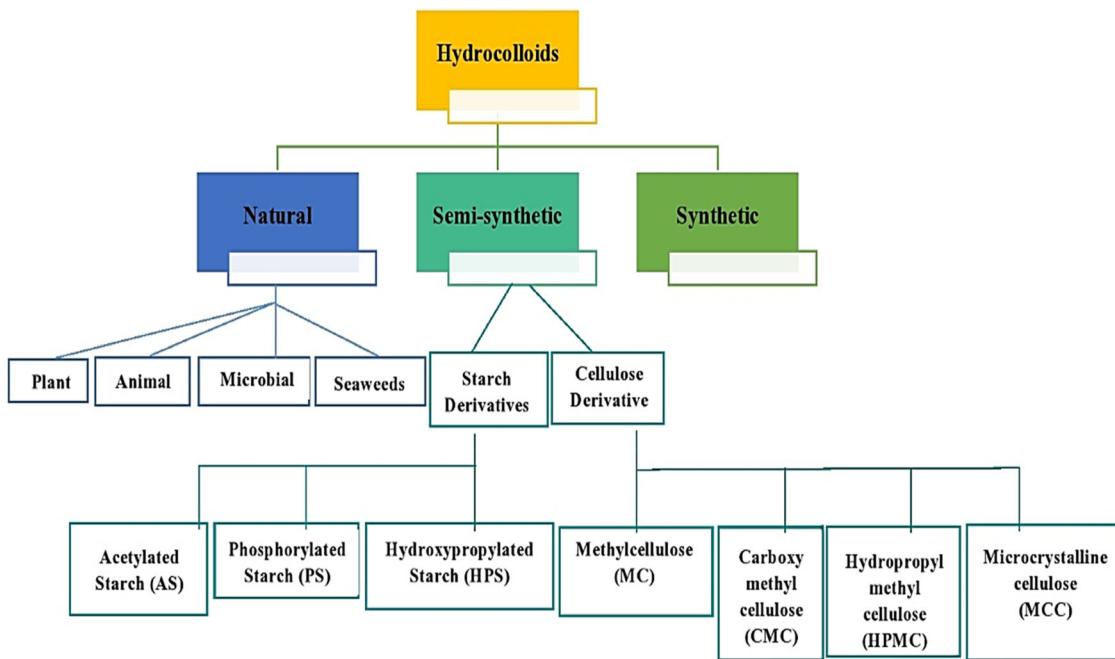
The use of hydrocolloids in food, biomedical, and pharmaceutical applications from various sources has been studied for several years (Gonzalez-Henriquez, Sarabia-Vallejos, and Rodriguez-Hernandez 2019). In the coming ten years, the international food hydrocolloid market will increase its value by at least 50% according to various projections and forecasts in the industry. The hydrocolloid market is estimated to reach about ten billion USD by 2021, up almost 17% in the year 2017–2021 over the forecast period. The Western Europe comprises the largest business sector representing 41.5% of the worldwide market (Martau, Mihai, and Vodnar 2019). This development is a direct result of the expanding utilization of hydrocolloids.

Functional properties continue to be the most conventional applications of hydrocolloids in the food business. Hydrocolloids use have been developed into a dynamic area such as in encapsulation of prebiotics and probiotics, bio-active compounds, food additives as well as nutrients. They are also widely used as edible films or coatings of different food products in order to improve its functionality. At present, hydrocolloids gives extraordinary unique technological attributes that could not be accomplished by regular strategies in the fields of nanotechnology. Pectin, inulin, b-glucan and resistant starch, for example, improves health and nutritional benefits such as effects on metabolic and chronic diseases and/or prebiotic activity is a further new utilization of food hydrocolloids.

## Classification of hydrocolloids

Hydrocolloids are categorized according to their origin as natural, semi-synthetic, and synthetic as shown in Figure 1. Natural hydrocolloids are hydrophilic polymers that are derived from natural sources such as plants, animals, micro-organisms and seaweeds. In contrast, semi-synthetic hydrocolloids are the modification of naturally derived hydrocolloids, while synthetic hydrocolloids are completely synthesized from petroleum-derived base materials by chemical processes to produce a product with structure similar in structure to natural polysaccharides.

Natural hydrocolloids are the most widely preferred in the food industry for improving the stability, functionality,



**Figure 1.** Classification of hydrocolloids.

quality, safety, nutritional and health benefits of various food products compared to semi-synthetic and synthetic hydrocolloids in the last few years due to the following distinct advantages such as:

- Extracted from renewable sources
- Readily available and easy to handle
- Biocompatible
- Non-toxic
- Capable of physical and chemical modification
- Eco-friendly and cost-effective
- More acceptance by the public due to numerous health benefits

### Naturally derived edible hydrocolloids

Natural hydrocolloids can be produced from two major macromolecules i.e., proteins or carbohydrates ingested by human beings every day. The natural hydrocolloids are categorized based on their origin as shown in Figure 2.

#### Natural algal seaweed derived edible hydrocolloids

Seaweeds provide an abundance of marine renewable resources that have been used in Asian countries and traditional medicines worldwide and play an important role in foods in ancient times (Khalil et al. 2018).

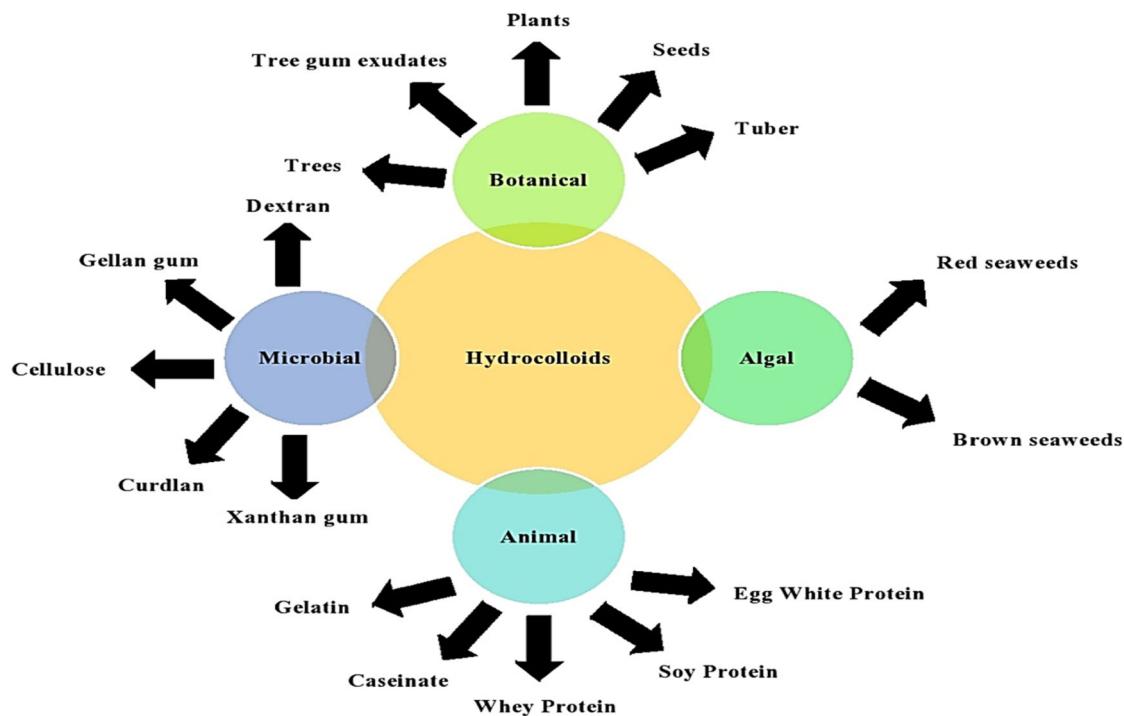
There are four different classification of seaweeds based on the pigments: red, brown, blue and blue-green. The important sources of hydrocolloids are red (*Rhodophyceae*) and brown (*Phaeophyceae*). The former include agar and carrageenan while latter include alginate are the most widely used in the food industry as stabilizers, thickeners, emulsifier and fillers (Gade, Tulasi, and Bhai 2013; Rhein-Knudsen, Ale, and Meyer 2015; Makkar et al. 2016). Due to

their excellent and unique properties of hydrocolloids, different sectors are replacing synthetic hydrocolloids in the near future.

#### Red seaweed: Agar

Agar originate mainly from red algae (agarophytes) of genera *Gelidium* and *Gracilaria* (McHugh 2003). It contains two significant classes of polysaccharide: agarose and agaropectin. Agarose is neutral or low sulfated/methoxy substituted constituting 70% of the mixture exhibiting high gelling property while agaropectin, is charged, heterogeneous and highly sulfated responsible for thickening property (Khalil et al. 2018). The balance of agarose-agaropectin balance varies with the seaweed species and condition of isolation (Armisen and Galatas 2009). Agar is chemically a linear galactan consisting of alternating units of  $\beta$ -D-galactopyranose and 3,6-anhydro- $\alpha$ -L-galactopyranose linked by  $\alpha$ -(1→3) and (1→4) glycosidic linkages, forming the backbone of two alternating disaccharide, agarobiose and neoagarobiose (Alba and Kontogiorgos 2018).

Agar is a more powerful cold-set gelling agent that its aqueous solution undergoes a sol-gel transition process upon cooling. Above sol-gel temperature, agar exhibits a random-coil conformation in solution and changes structure to double helix upon cooling. The structure is stabilized by the aggregation of the helices and hydrogen bonds between structural water and galactose. Agar is the first food hydrocolloid additive which has been accredited by Food and Drug Administration (FDA) as GRAS (Generally Recognized as Safe) in food industry for its many characteristics features such as high gelling capacity, firm texture, high thermal tolerance capacity, wide pH stability, solubility in concentrated sugar solutions, minimal reactivity with other foodstuffs and perfect gel (Stanley 2006; Imeson 2010). Approximately, 80% of global agar is utilized in food applications, while 10–20%



**Figure 2.** Classification of natural hydrocolloids on basis of origin.

is utilized in pharmaceutical and biotechnology industries applications (Pereira 2011).

#### **Red seaweed: Carrageenans**

Carrageenans belong to the family of linear, sulfated, water-soluble, negatively charged marine hydrocolloid polysaccharide derived from red seaweed (*Rhodophyceae*) that comprises principally of alternating units of 3-linked- $\beta$ -D-galactopyranose and 4-linked  $\alpha$ -D-galactopyranose which form repeated disaccharide units (Imeson 2000). Carrageenan is conventionally divided into six types, namely kappa- ( $\kappa$ ), iota- ( $\iota$ ), lambda- ( $\lambda$ ), mu ( $\mu$ ), nu ( $\nu$ ), and theta ( $\theta$ ) depending on the number and position of sulfate groups as shown in Figure 3 (Ali and Ahmed 2018). Among these six types, kappa, lambda, and iota are the most idealized form of carrageenan carrying 1, 2 and 3 sulfate groups respectively exhibiting different structural features (Maolin et al. 2000).

Carrageenan varies in chemical composition among red seaweed species and extraction method. *Kappaphycus alvarezii* and *Eucheuma denticulatum* species are primarily used to isolate  $\kappa$ - and  $\iota$ -carrageenans have been isolated primarily, while *Gigartina skottsbergi* and *Sarcothalia crispata* is used to extract lambda carrageenan (Imeson 2009).  $\kappa$ - and  $\iota$ -carrageenans form reversible gels using ionotropic gelation mechanism coupled with a cold-set process, while  $\lambda$ -carrageenan does not through sol-gel transition because of higher sulfate content that restrains the development of helicoidal structure (Saha and Bhattacharya 2010).  $\kappa$ - and  $\iota$ -carrageenans has random coil conformation in solutions and upon cooling it endure coil-helix conformational transition under appropriate salt condition ( $K^+$  or  $Ca^{2+}$ ) cations which shape helix formation and also maintains tighter aggregation linkages by neutralizing the negative charge of

the sulfate groups with the position cations in arrangement framing junction zones (Imeson 2000). Moreover, additional ions to the gelling system improves helix stability and encourages tighter aggregation of the helix that is critical for the gelation process (Morris, Rees, and Robinson 1980).

With the decrease of sulfate groups in the repeating unit produces inflexible, brittle gels in case of  $\kappa$ -carrageenan (1 sulfate group per repeating unit).  $\iota$ -carrageenan (2 sulfate groups per repeating unit) display higher helix stability with divalent ions such as calcium and forms soft, reversible, elastic, and cohesive gel while  $\lambda$ -carrageenan (3 sulfate groups per repeating unit) does not gel since higher number of sulfate groups contribute to gel inhibition and resulting in good solubility hence used as a thickener. Carrageenan is profoundly esteemed for its capacity to create gels with a wide texture spectrum due to the variations in their sulfate groups and anhydro-bridges (Imeson 2000). However, it is a weaker gelling agent than agar. Carrageenan is extensively used in the food industry particularly in dairy industry as a gelling agent, thickener and stabilizer (Alba and Kontogiorgos 2018).

#### **Brown seaweed: Alginate**

Alginate is primarily isolated from brown seaweed (*Phaeophyceae*) specifically from the outer layer of brown algae cell wall. Commercially available sources of alginate include species like *Laminaria digitata* and *Ascophyllum nodosum*, *Laminaria hyperboreana*, *Macrocystis pyrifera*. Alginate is a straight, unbranched polymers comprising of a blend of monomeric uronic acids i.e.,  $\beta$ -D-mannuronic acid (M) and  $\alpha$ -L-gluronic acid (G) linked by (1 $\rightarrow$ 4) glycosidic bonds as shown in Figure 4, arranged in an asymmetrical pattern of varying proportions depending on seaweed source, method of and harvest time (Rhein-Knudsen, Ale, and Meyer 2015). The M/G

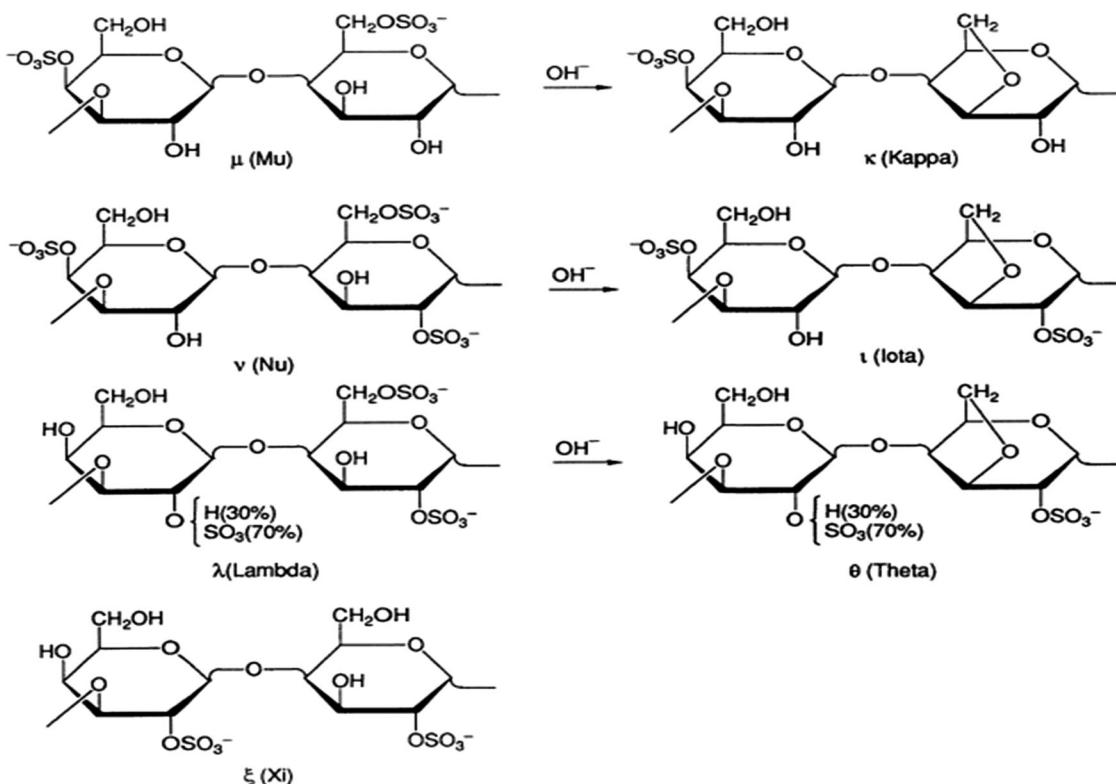


Figure 3. Carrageenan repeating unit, BeMiller and Whistler (2012).

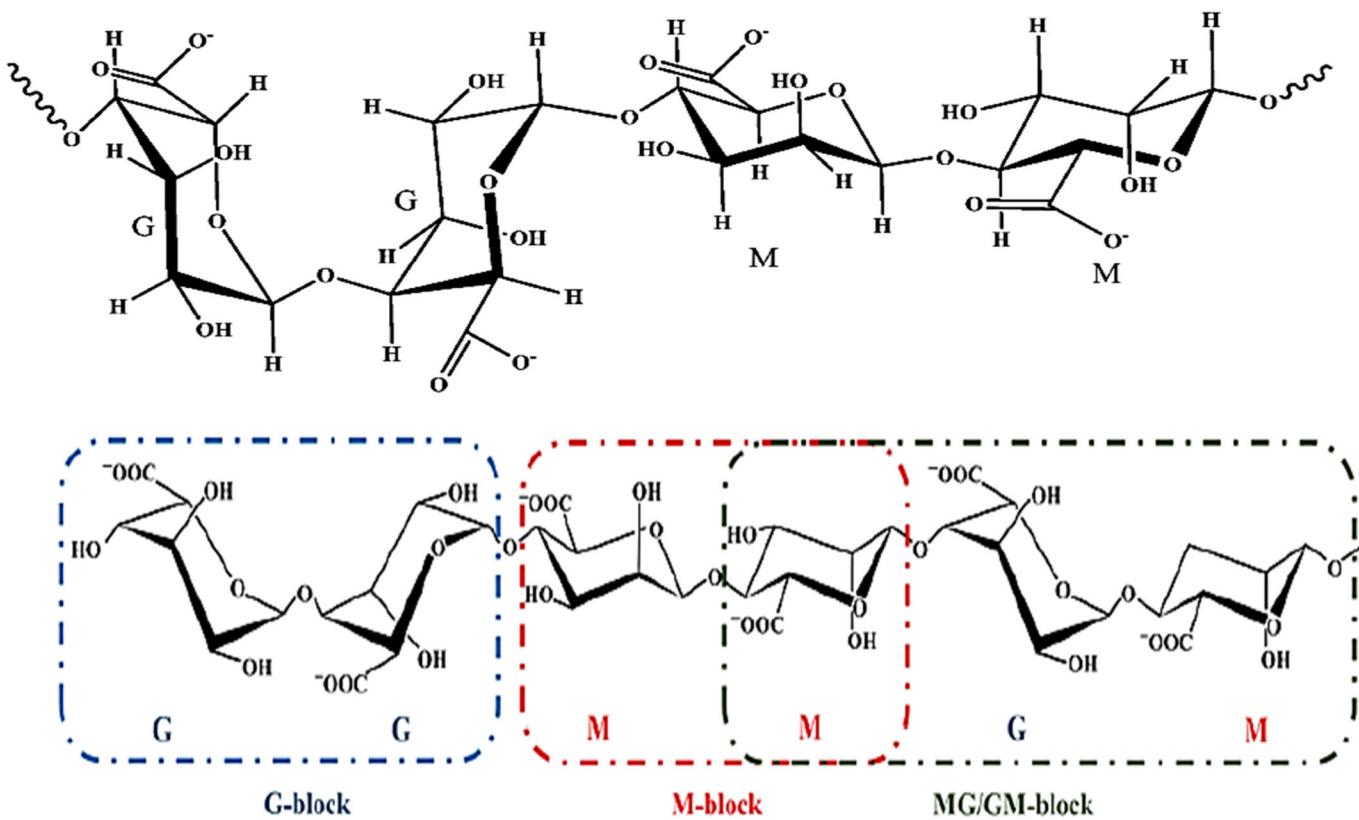


Figure 4. Chemical structure of alginate, Ali and Ahmed (2018), Martau, Mihai, and Vodnar (2019).

ratio and block structure importantly affect alginate's physiochemical properties. In general, more stronger, transparent and brittle alginate gels can be accomplished by increasing the

gluronic acid (G) content or molecular weight. Inversely, the high amount of alginate-M blocks can give rise to more flexible gels (Szekalska et al. 2016; Fertah et al. 2017).

Alginates are commercially accessible as sodium, potassium, or ammonium salts (Burey et al. 2008). Alginate structure gels through an ionotropic process in the polymer chain by the involvement of inter-chain ionic binding between guluronic acids blocks (G-blocks) with the divalent cations such as calcium, barium and strontium giving rise to a three dimensional network (Draget 2000). Such restricting zones between the G-blocks are generally alluded to as an “egg-box” model and thus alginates with high G-block content evoke stronger gels. Alginate gels can be impacted by gelation temperature, alginate concentration and ion concentration (Draget 2000). Alginate has a broad range of applications in the food and pharmaceutical industry due to its wide range of functionality.

### **Natural botanical derived edible hydrocolloids**

The need for hydrocolloids from botanical sources such as plant cell wall, tree exudates, and endosperm of seeds is higher than animal sources due to greater benefits and consumer friendly nature (Razavi 2019). Some of these are discussed below:

#### **Trees: cellulose**

Cellulose is the most abundant, renewable and inexhaustible raw material in the cell walls of higher plants, green algae, membranes of fungi and *Acetobacter xylinum* and related species (Chang and Zhang 2011; Ali and Ahmed 2018). It is a high molecular weight polymer, composed of  $\beta$ -D-glucopyranose units joined by (1 $\rightarrow$ 4) glycosidic bonds (Bracone et al. 2016; Gutierrez 2017). Cellulose and its derivatives are fully exploited, however only physically and chemically modified cellulose finds their full usage under different fields (Milani and Maleki 2012). There are four water-soluble cellulose derivatives that have been widely used as edible hydrocolloids such as methyl cellulose (E-461), hydroxypropyl cellulose (E-463), hydroxypropyl methylcellulose (E-464) and carboxymethyl cellulose (E-466) (Shit and Shah 2014).

Cellulose derivatives exhibit unique thermo-gelation properties and hence widely used in food and other industry as emulsifying agents, thickening agent and gelling agent due to their low cost, bio-compatibility, biodegradability, bio-adhesiveness, and nontoxicity that will become the leading resource in the future (Chang and Zhang 2011; Shi et al. 2014; Vlaia et al. 2016; Ali and Ahmed 2018).

#### **Plants: starch**

Starch serves as the principal food reserve polysaccharide in plants (Alvarez, Famá, and Gutiérrez 2017). It is primarily composed of amylopectin (70%–80%) and amylose (20%–30%) two distinct forms of molecules as shown in Figure 5. Amylopectin is a branched polysaccharide consisting 95%  $\alpha$ -(1 $\rightarrow$ 4) and 5%  $\alpha$ -(1 $\rightarrow$ 6) linkages while amylose is linear (1 $\rightarrow$ 4)-linked  $\alpha$ -D-glucan (Gutierrez et al. 2015). The edible starch has possesses similar characteristic to plastic such as tasteless, odorless, biologically absorbable, nontoxic, semipermeable to carbon dioxide, colorless, and oxygen

resistant that finds tremendous applications in biomedical, food packaging, pharmaceuticals, agriculture, personal care as well as food processing (Kennedy et al. 2011; Xiao 2013; Ismail, Irani, and Ahmad 2013).

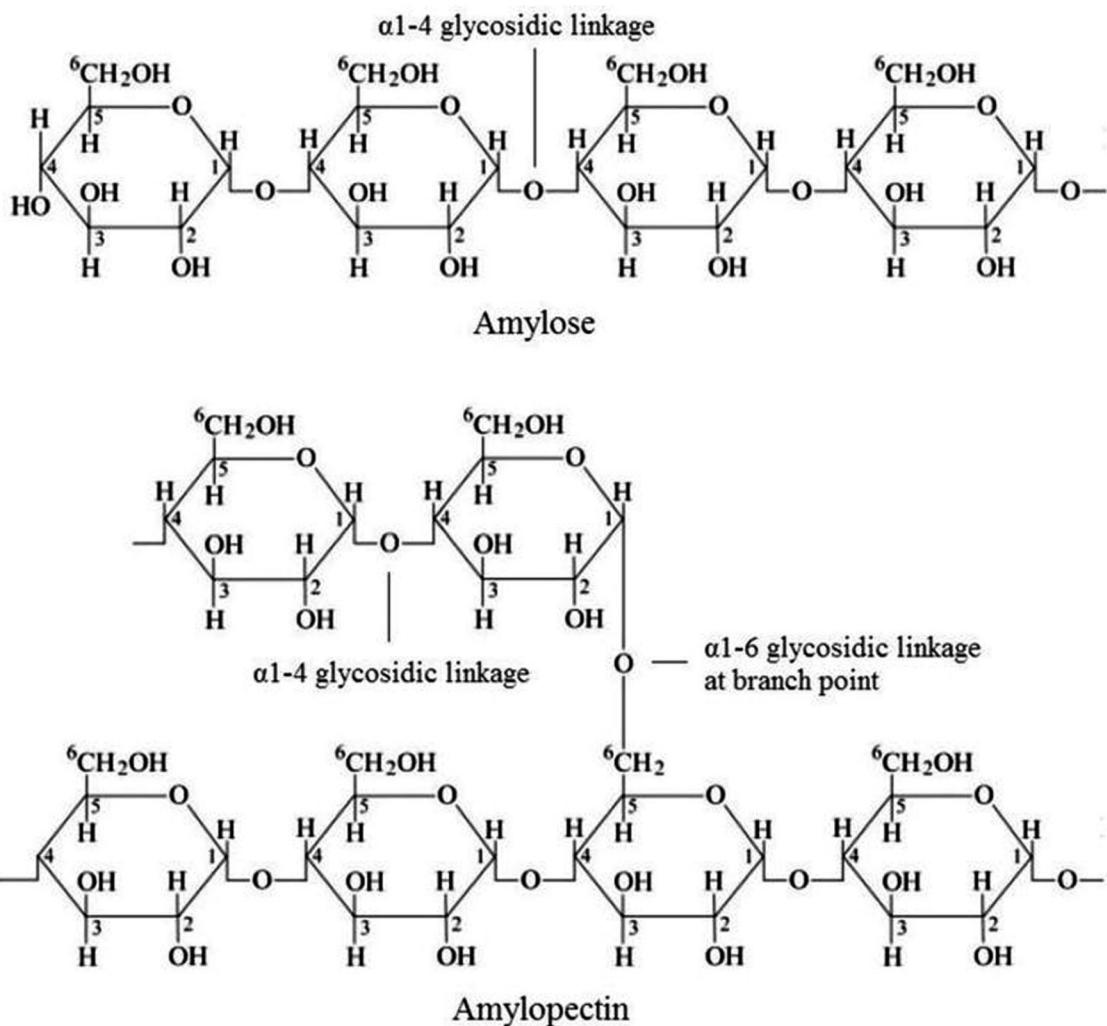
#### **Plants: pectin**

Pectin is a structural polymer which is widely distributed in the tissue of land plants, where it acts as an intercellular glue that strengthens the basic cellulose structure of plant cell walls and middle lamellae (May 2000). It is often derived from fruits and vegetables (1%), apple pomace (15% pectin), citrus peels (30%) and sunflower heads or sugar beet residues under acidic conditions (pH 1.5–3) at temperature 60 to 100 °C (Hoefler 2004; Mikuš, Valík, and Dodok 2011). It is a linear heteropolysaccharide consisting 65% of D-galacturonic acid units combined with  $\alpha$ -(1, 4) bonds that is required for commercial use as a food additive.

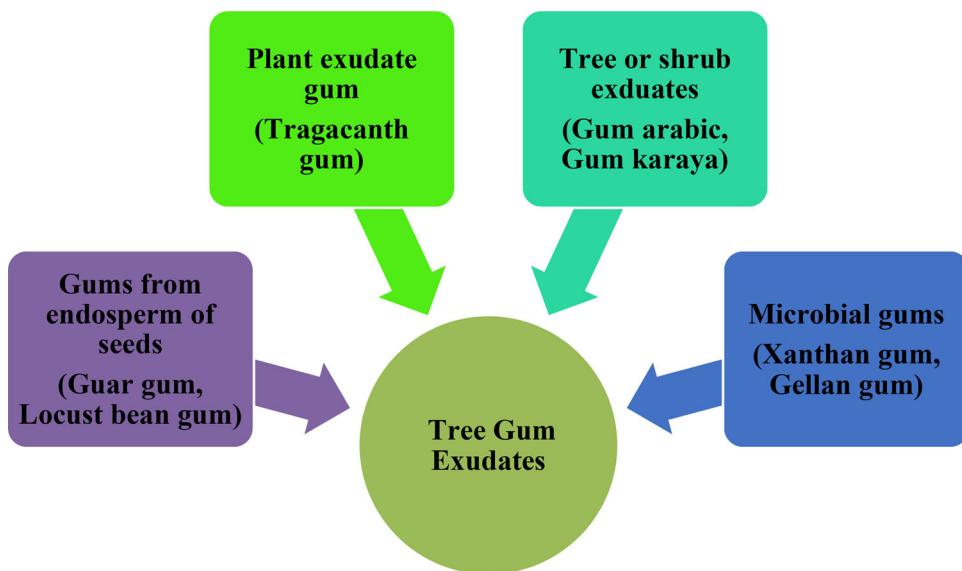
The pectins are classified according to the degree of esterification (DE), namely high-methoxyl pectin (HM) and low methoxyl pectin (LM) with DE > 70% and methoxyl content >7% and DE < 50% and methoxyl content <7% respectively. They can be amidified or non-amidified (Hoefler 2004). LM pectin gels by ionotropic gelation process in presence of divalent ions like  $\text{Ca}^{2+}$  and forms “egg-box” model similar to the network structure formed in alginate gels (Burey et al. 2008), while high HM pectins gel at high soluble solids and low pH (Hoefler 2004) as encountered in jam preparation (Nussinovitch 1997). The gelling properties of LM pectin gels are affected by ion concentration, hydrocolloid concentration and the method of preparation similar to alginates. Pectins are soluble in water and insoluble in most organic dissolvent. Solubility decreases in water with growing molecular weight and degree of esterification of carboxyl groups and hence not employed as a thickening agent (Phillips and Williams 2009; Hoefler 2004). Pectin is a negative charge in neutral conditions, thus associated with positively charged polymers (proteins). It is used in foods and pharmaceuticals as gelling, thickening, and stabilizing agent. HM pectin is used in the preparation of high sugar content products such as jellies, jams and confectionery products to improve its structure, bite, and baking stability. It is also used as a non-gelling stabilizer in soya drinks, acidified dairy or fruit beverages. LM pectin, on the other hand, thickens fruit-based ripples and pumpable toppings. Other uses include yogurt and cold-setting milk desserts, fat substitutes in sauces, salad dressings, ice cream, processed meat and cheese products and spreads.

#### **Tree gum exudates**

Natural exudate plant-based polysaccharide gums are produced as a result of stress by the plants. They are mainly categorized into four groups according to their origin as shown in Figure 6. Many gums are available nowadays, but only few gums are important that have been used in various food and pharmaceutical applications such as gum arabic, gum tragacanth, gum karaya, and gum ghatti.



**Figure 5.** Structure of starch-amylose and amylopectin unit, Nawaz et al. (2020).



**Figure 6.** Origin based naturally derived tree gum exudates.

**Tree gum exudates: gum arabic.** Gum arabic or acacia gum exudate is a naturally edible, dried, branched multi-functional heteropolysaccharide hydrocolloid obtained from

*Acacia Senegal* and *Acacia Seyal* stems and branches of Leguminosae family (Renard, Lavenant-Gourgeon, et al. 2006). The arabinogalactan protein hydrocolloid is either

neutral or slightly acidic. This hybrid polyelectrolyte is composed of small portion of protein which is responsible for emulsifying properties as well as polysaccharides sub-units (6 carbohydrate moieties) with calcium, magnesium and potassium salts (Patel and Goyal 2015; Musa, Ahmed, and Musa 2018). This hydrocolloid polysaccharide consists of 1,3-linked  $\beta$ -D-galactopyranosyl units (main chain) linked to the side chain by 1,6-linkages (Ali, Ziada, and Blunden 2009). Owing to its molecular structure and conformation, it is widely used for flavor stabilization, inhibit flocculation and coalescence of carbonated beverage and flavor oil emulsions due to its stability in acidic condition.

**Tree gum exudates: gum karaya.** Gum karaya is a dry exudate derived from *Sterculia urens* or *Cochlospermum gossypium*, also known as Sterculia gum or Indian gum. It is a complex, branched and partially acetylated polysaccharides composed of D-galactose, L-rhamnose, L-glucuronic acid and D-galacturonic acid (Phillips and Williams 2009; Hoefer 2004). Rhamnogalacturonan backbone chains consist of a mixture of  $\alpha$ -(1,4)-linked D-galacturonic acid and  $\alpha$ -(1,2)-linked L-rhamnosyl residues. The side chain consists of (1 $\rightarrow$ 3)-linked  $\beta$ -D-glucuronic acid, or (1 $\rightarrow$ 2)-linked  $\beta$ -D-galactose on the segment of galacturonic acid unit in which one half of rhamnose is substituted by (1 $\rightarrow$ 4) linked  $\beta$ -D-galactose (Milani and Maleki 2012). 60% neutral saccharide residues (galactose and rhamnose), 40% acidic residues (galacturonic and glucuronic acid) and 8% of acetyl groups are present in commercially available gum karaya (Vinod et al. 2010). At low concentrations (<0.02%), gum karaya is poorly soluble and thus constitutes solutions. In comparison to this, viscous colloidal dispersions occur at higher concentrations (up to 5%). It is used as an emulsifier, moisture controller and foam stabilizer to increase dough stability and also prolong shelf-life of bakery products (Bárcenas, De la O-Keller, and Rosell 2009).

**Tree gum exudates: gum ghatti.** Gum ghatti is an indistinct clear gum exudate of *Anogeissus latifolia* tree from Combretaceae family. Gum ghatti comprises of monosaccharide variables such as L-arabinose, D-galactose, D-mannose, D-xylose, and D-glucuronic acid in the proportion of 10:6.2:1:2, with traces of 6-deoxyhexose.

**Tree gum exudates: tragacanth gum.** Gum tragacanth is an air hardened gum exudate obtained naturally from branches and trunk of *Astragalus gummifer* or its species. Tragacanth gum is a highly branched, acidic heteropolysaccharide consists of repeating units of (1 $\rightarrow$ 6)-linked D-galactosyl backbone to which highly branched L-arabinose side chains joined by (1 $\rightarrow$ 2), (1 $\rightarrow$ 3) and/or (1 $\rightarrow$ 5) linkages. It contains 30%–40% water-soluble fraction (Tragacanthin) and ~60 to 70% water-insoluble fraction (Tragacanthic acid) of the entire gum. The continued use of the gum is the result of its unique functional properties combined with a high degree of stability in a wide range of conditions despite the availability of alternative materials.

**Seed endosperm gum: guar gum.** Guar gum is obtained from endosperm of seeds of drought resistant guar plant

(*Cyamopsis tetragonolobus*) or cluster bean. It is a nonionic galactomannan polysaccharide (Achayuthakan and Suphantharika 2008) composed of D-mannose and D-galactose in ratio of 1.6:1. A linear backbone of mannose units bound to  $\beta$ -(1 $\rightarrow$ 4). Single terminal D-galactose units are linked to the main backbone by  $\alpha$ -(1 $\rightarrow$ 6)-glycosidic bonds to the 4, 6-mannose units. Almost every second mannose unit is connected to the unit of galactose. Wide guar branching is responsible for its simpler hydration properties and also for its higher water activity and stability in pH 4–10 solutions. Guar gum is commonly used as a binder and thickener in the food industry.

**Seed endosperm gum: locust bean gum.** Locust bean gum, also known as Carob gum is obtained by milling the endosperm of seeds of carob trees (*Ceratonia siliqua*). It is a neutral galactomannan polysaccharide consisting of D-mannose and D-galactose with an average molecular ratio of 3.5:1 (Achayuthakan and Suphantharika 2008). The molecule comprises a linear backbone of  $\beta$ -mannose units linked by (1 $\rightarrow$ 4) glycosidic bond. In this, every fourth unit of mannose is connected by  $\alpha$ -(1 $\rightarrow$ 4) to the galactose unit. The properties of guar gum resembles with locust bean gum thus both can be used as each other alternatives in the same applications as where synergistic relations give additional benefits like in sorbets, ice-creams, dairy desserts etc.

**Seed endosperm gum: tara gum.** Tara gum also known as Peruvian carob bean gum obtained by grinding the endosperm portions of the seeds of tara tree *Caesalpinia spinosa*. It is a neutral galactomannan polysaccharide made up of linear main chain of  $\beta$ -(1 $\rightarrow$ 4) linked mannose units with  $\alpha$ -1-6-linked side chains of a single galactose unit. The mannose to galactose ratio (M/G) is 3:1. Its properties are similar to guar gum and locust bean gum. It does not form gels by itself, however, shows gelation property with xanthan gum but marginally weaker than xanthan with locust bean gum. It is used as a thickener and stabilizer in many foods in food and industrial application.

**Seed endosperm gum: tamarind gum.** Tamarind gum is a galacto xyloglucan derivative isolated from its seed kernel of *Tamarindus indica*. It is a highly branched polysaccharide consisting of glucose, galactose and xylose in the molecular ratio of 3:2:1. The linear main chain is linked with  $\beta$ -(1 $\rightarrow$ 4) glucose units. It is primarily used as a stabilizer, thickener, binder and gelling agent in the food and pharmaceutical industries (Wustenberg 2015).

#### **Tuber: Konjac Mannan**

Konjac Mannan is a water-soluble vegan polysaccharide substitute for gelatin obtained from konjac tubers. It consists mainly of a random chain of  $\beta$ -(1 $\rightarrow$ 4)-linked D-glucopyranose and  $\beta$ -D-mannopyranose sugars (Wustenberg 2015). On an average, the mannose to glucose molecular ratio is 1.6:1. It is widely popular in the food and pharmaceutical industry due to its harmless, biocompatible and organically

degradable nature (Yang et al. 2017). Konjac is used for shelf-life extension, adhesion for coatings and binding in bakery, pasta, desserts and restructured meat or vegetable products.

### **Natural microbial derived edible hydrocolloids**

Extracellular polysaccharides produced by microorganisms in which xanthan gum accounts for over 90% of the global food market for microbial hydrocolloids. Curdlan, dextran, phullan, gellan gums are other types of microbial hydrocolloids (Razavi 2019).

#### **Xanthan gum**

Xanthan gum is an extracellular anionic polysaccharide formed by fermentation of glucose or sucrose by bacterium *Xanthomonas campestris* (Achayuthakan and Suphantharika 2008). The principle structure includes a cellulose backbone with  $\beta$ -D-glucose units which is linked by (1 $\rightarrow$ 4) glycosidic linkage. It is substituted by tri-saccharide side chain on alternate glucose residues, which consists of two mannose units separated by glucuronic acid (Milani and Maleki 2012). About 50% of the terminal mannose units are bound to a pyruvate group and the non-terminal residues (usually acetyl group) that is largely dependent on *X. campestris* strain resulting in different viscosities of xanthan solution.

#### **Curdlan**

Curdlan is an extracellular polysaccharide obtained by non-pathogenic bacteria *Agrobacterium biovar* and mutants of *Alcaligenes faecalis* var. *myxogenes* are produced by conventional fermentation processes. It is a high molecular weight glucose polymer of linear  $\beta$ -(1 $\rightarrow$ 3)-glucan and does not have any branches. It forms irreversible gel on heating. It is insoluble in water, edible, biodegradable and impermeable to oxygen films with strength between cellulose and amylose. It has numerous applications as a gelling agent in food and pharmaceutical industries and can replace agar and gelatin in production of jam, jellies etc.

#### **Dextran**

Dextran is produced by fermentation of the disaccharide sucrose by bacterial enzymes of genus *Leuconostoc* or *Streptococcus*. It is a neutral highly branched polysaccharide consisting of glucose units with glycosidic bonds occurring as  $\alpha$ -(1 $\rightarrow$ 4) or  $\alpha$ -(1 $\rightarrow$ 3). For making protective coatings, dextran is suitable.

#### **Gellan gum**

Gellan gum is a *Sphingomonas elodea* produced polysaccharide. Gellan molecular structure is a straight chain consisting of glucose, rhamnose and glucuronic acid as repeating units. Two acyl substituents i.e., acetate and glycerate are available in its native or high-acyl form. Both substituents are present on the same glucose residue and, on average, there is one glycerate per repeat and one acetate per two repeating units. The acyl groups are absent in low acyl groups. The involvement of

acyl groups in native gellan interferes with the aggregation process exhibiting weaker gel, while the side chains also interfere with the cation-induced aggregation of branched gellan variants allowing only "weak gel" formation. The double helix polysaccharide chains aggregate into weak gel structures supported by van der Waals attractions on cooling of gellan solutions. The double helices, however, contribute to the development of strong gels in the presence of appropriate cations ( $\text{Na}^+$  or  $\text{Ca}^{2+}$ ).

### **Natural animal derived edible hydrocolloids**

Animal hydrocolloids originate from animal bones and skins such as swine, cattle etc. Gelatin is the most widely used hydrocolloid which represents 99% of the overall market animal hydrocolloids. Whey protein, chitosan are several other hydrocolloids obtained from animals.

#### **Gelatin**

Gelatin is a protein-based biodegradable, and non-immunogenic hydrocolloid polymer obtained by partial controlled acid or alkaline hydrolysis of animal connective tissue (collagen) found in skins or bones of different animal species (beef, pork, fish and poultry). Gelatin molecules contain repeating sequences of glycine-proline-hydroxyproline amino acids that extends over the polymer chain to form a triple helical structure (Clark and Ross-Murphy 1990), thus exhibiting good flexibility, reversibility, and transparency to gelatin-based gels. Its mechanical and thermal stability, however, is poor and can be improved by chemical modifications (Banerjee and Bhattacharya 2012; Ramos et al. 2016).

Gelatin forms thermally reversible gel by cold-set process in aqueous solution (Djabourou 1991). Gelatin solution behaves like a conventional synthetic polymer above 40°C. Gelatin gels are typically produced at higher concentrations for food products (1–5%) w/w than agar, alginate, carrageenan, and pectin (Tosh et al. 2003). Gelatin gelation properties depend on concentration of gelatin, pH, cooling rate used during gelation and gelling temperature. It is widely used in the food industry due to its gelling, good flexibility, reversibility, transparency, forming property (Chen, Remondetto, and Subirade 2006; Ali and Ahmed 2018) and non-food fields due to its low immunogenicity level and low cytotoxicity (Baziwane and He 2003; Karim and Bhat 2008).

#### **Whey protein**

Whey protein or serum protein, main by-product of cheese manufacturing have high nutritional value and biocompatibility and therefore widely used in food products due to its large range of applicability to forms gels, emulsion, and gelled emulsion (Remondetto, Beyssac, and Subirade 2004, Joshi et al. 2020).  $\alpha$ -lactalbumin,  $\beta$ -lactoglobulin, and bovine serum albumin are the principal components of whey protein. Whey proteins gels exhibit good pH sensitive swelling capability above its isoelectric point (Gunasekaran, Ko, and Xiao 2007).

It is, however, also found that its use is limited in industrial applications due to its brittle nature. Low molecular weight substances, for example, glycerol have been used as a plasticizer in order to make them flexible (Schmid et al. 2013). Temperature and protein content have significant effect on the viscoelastic properties of whey protein gels (Katsuta, Rector, and Kinsella 1990). The microgel whey protein particle is formed by involvement of some interaction between polymer chains such as electrostatic, hydrophobic, and cross-linking disulfide bridges on heating (Sarkar et al. 2016) that exhibit appreciable property of coalescence resistance and thus as a promising candidate for food and innovative pharmaceutical applications.

### Chitosan

Chitosan, which is the structural element of crustacean exoskeleton such as lobster, shrimp and crab, is another most abundant and highly important polysaccharide after cellulose produced from chitin (Gutierrez 2017). Structurally, it is a straight chain polymer, consisting of  $\beta$ -(1→4)-D-glucosamine and N-acetyl-D-glucosamine units formed by partial deacetylation of chitin as shown in Figure 7. The chitin molecular structure is similar to cellulose, except that hydroxyl groups at O-2 of the glucose unit are replaced by N-acetyl amino groups, thus replacing cellulose in many lower plants such as fungi, yeast, green, brown, and red algae. Chitin forms a highly ordered crystalline structure stabilized by multiple

intermolecular hydrogen bonds. Chitosan is water soluble hydrocolloid. Also, it is the only polysaccharide bearing a positive charge or cationic amino group that can interact easily with other negatively charged or anionic molecules forming gels. It is a popular hydrocolloid nowadays due to its antibacterial property, nontoxicity, biodegradability (Ahmadi et al. 2015). It is not digested by humans but can be used as a source of dietary fiber.

### Functionality of hydrocolloids

The key factor for the widespread use if hydrocolloids in various applications such as food, pharmaceutical, biotechnology, agricultural and chemical industries is their physiological understanding “natural” materials and their capacity for altering the rheology of the food system and numerous other potentially positive features (Gupta and Abu-Ghannam 2011). Hydrocolloids possess a wide range of functional properties. They are used in foods for two main reasons:

- Physical functionality that include behavior (viscosity or gelation) and mechanical solid property (texture). The changes in the characteristics of the food system alters its sensory properties, and henceforth, hydrocolloids are utilized as significant food additives for explicit purposes (Milani and Maleki 2012; Goff and Guo 2019)
- Nutritional benefits (Goff and Guo 2019)

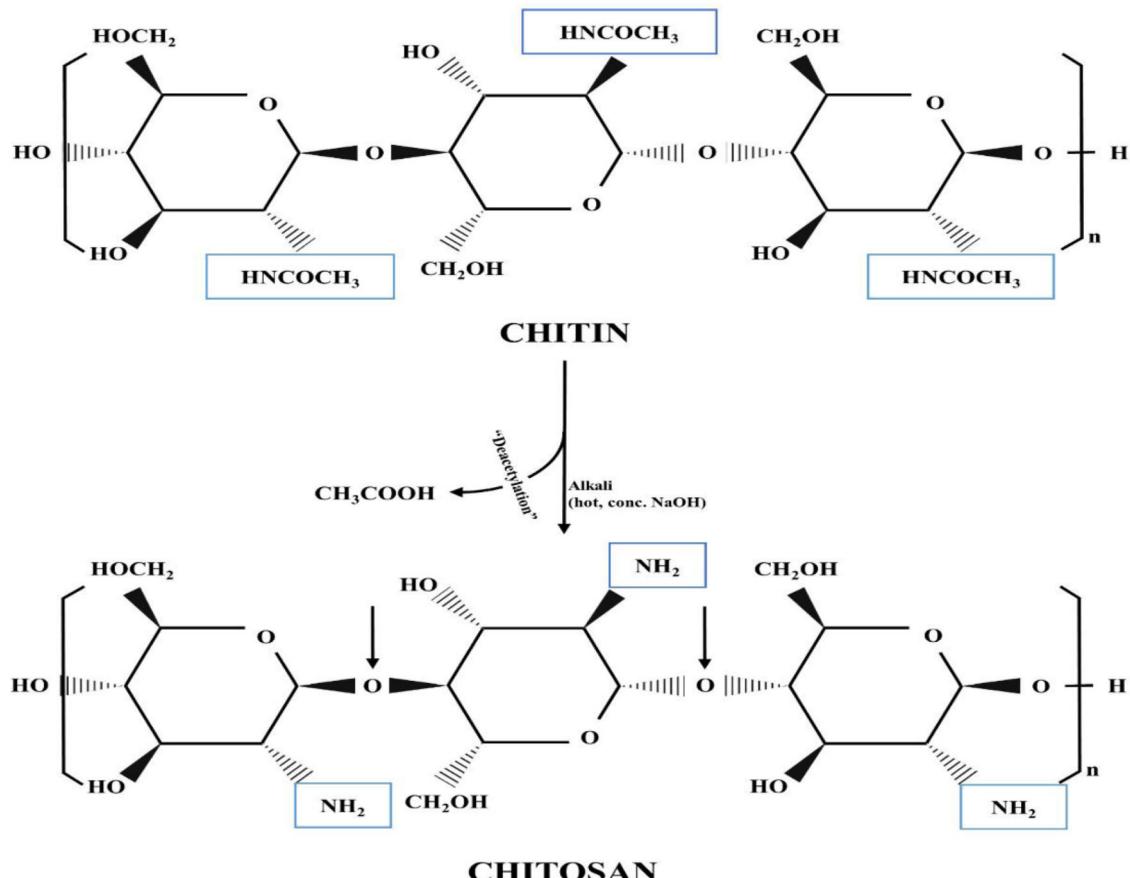
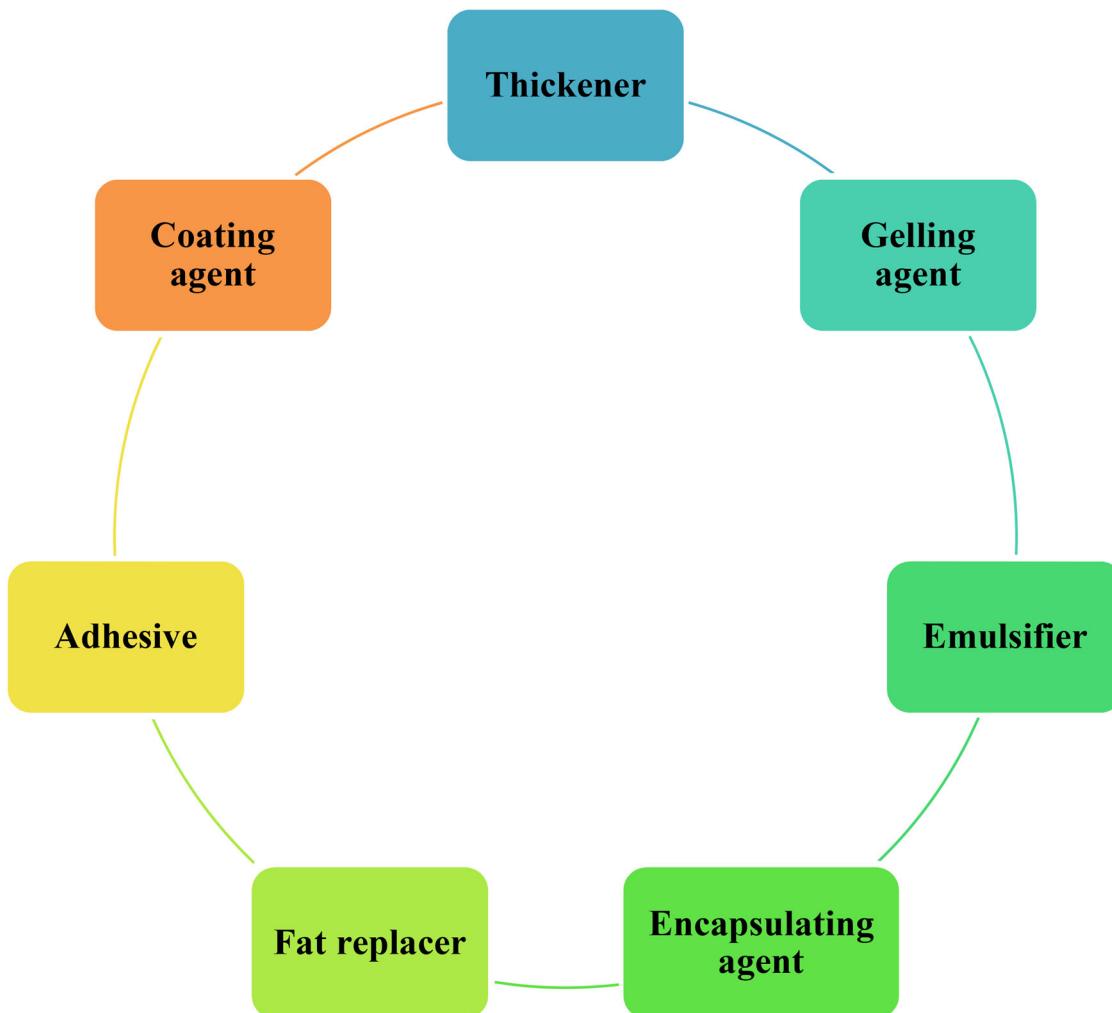


Figure 7. Structure of chitin and chitosan, Martau, Mihai, and Vodnar (2019).



**Figure 8.** Functional Properties of Natural Edible Hydrocolloids.

A significant number of hydroxyl groups, leading to higher H-bonding interactions in the aqueous system resulting in rheological behavior of the hydrocolloids (Razavi 2019). These behaviors are an indication of the chemical structure and conformation of the polymer in solution and in turn are used to provide functionalities such as structure development, modification of textural properties of the food system, or the extension of shelf-life (Goff and Guo 2019).

Nowadays, hydrocolloids are in demand to develop a countless range of properties as shown in Figure 8 and mentioned in Table 1 and their applicability in various fields like food, biomedical, pharmaceutical, nanotechnology, edible food packaging materials, bio-plastics and edible cutlery as mentioned in Table 2 (Shan 2016; Chavan, Singh, and Kaur 2018).

### **Thickening property**

Changing the texture and/or viscosity of the food system can contribute to the modification of the sensory properties and hydrocolloids are therefore used to achieve specific purposes to be used as food additives. Thickening is one of the property of the hydrocolloid that involves nonspecific entanglement of conformationally disordered polymer chains with solvent which occur only above critical concentration

known as overlap concentration ( $C^*$ ). Below the critical concentration, the polymers chains act as random coils of disordered arrangement and thereby, behave as newtonian fluid that does not exhibit thickening property whereas molecules are less mobile and start come in contact at high concentration thereby, restricting the movements due to entangled network and results in thickening (Phillips and Williams 2009).

The thickening effects of hydrocolloids are affected greatly by hydrocolloid type (hydrodynamic size of polymer and molecular mass), concentration, food system in which it is used, charge density, chain rigidity, pH and temperature of the food system. Ketchup is one of the most common food products used to influence its viscosity by hydrocolloid thickeners with few exhibiting high viscosity at low concentration, but mostly less than 1% (Glicksman 1982; Sahin and Ozdemir 2004). Gibiński et al. (2006) studied the thickening characteristics of sweet and sour sauces using various polysaccharide combination such as potato starch (3%) + xanthan gum (0.1%, 0.15%, 0.2%), oat starch (3%) + xanthan gum (0.1%, 0.15%, 0.2%), oat starch (3%) + oat hydrolysate (3%, 4%, 5%) and oat starch (3%), oat hydrolysate (2%) and xanthan gum (0.1%, 0.15%, 0.2%). Based on the effect of sensory properties and rheology, thickener performance was

**Table 1.** Properties of various natural edible hydrocolloids.

Type of Hydrocolloid	Chemical Composition	Characteristics	Type of Gelation and Mechanism of Gelation	Merits	Limitations	References
Agar Red seaweed extract ( <i>Gelidium</i> and <i>Gracilaria</i> species)	D-galactose ( $\beta\rightarrow 6$ ) + anhydro-L-galactose Low sulfate content (<4.5%), mostly (1.5%–2.5%)	• Opaque, yellowish aqueous solution • Insoluble in cold water • Soluble at temperature >80 °C • Gelling agent concentration 0.5%–2% wt/wt • Low dosage level in food, typical 0.5%–2%	Thermo-reversible gelation Molecules undergo a coil-helix transition followed by aggregation of helices by formation of hydrogen bonds	• High gel strength • Imparting firm texture • High heat tolerance ability • Stability under acidic conditions • High solubility in concentrated sugar solutions • Limited reactivity with other food components • Perfect gel reversibility • Resist high temperature • Effective in stalting • Prevent dehydration • Maintains structural integrity of food product • No impact of electrolytes	• Decomposition by heat + low pH (below pH < 4) • Insoluble in organic solvent and cannot form gels	Arnsen, Galatas, and Hispanagar (2000); Stanley (2006); Wustenberg (2015)
Carrageenan (most popular kappa, iota and lambda)	D-galactose + 3,6-anhydro—galactose joined by $\alpha-(1,3)$ and $\beta-(1,4)$ -glycosidic linkage	• Linear, anionic sulfated water soluble polygalactan (15%–40% ester sulfate content) • Average molecular mass >100 kDa • All carrageenan are soluble in hot water • Only kappa and iota are also soluble in cold water • Gelling agent concentration 0.5%–3% wt/wt • Dosage level used in food for iota is 0.005%–2% by weight • Stable within pH range 5 to 10 • $\iota$ -C: soft elastic texture, no syneresis, freeze-thaw stable gels, $\lambda$ -C: no gels, solutions are freeze-thaw stable	Thermo-reversible gelation Upon cooling, molecules undergo a coil-helix transition from a disordered random coil to the ordered helical followed by aggregation of helices to form double or triple helical structures. Presence of salts reduce electrostatic repulsion between chains promoting aggregation. $\kappa$ -C: strongest gels with K <sup>+</sup> $\iota$ -C: strongest gels with Ca <sup>2+</sup> $\lambda$ -C: no gelation	• Hygroscopicity • High shear stability • Stable viscosity within wide pH range (5–10) • High gel transparency	• Hydrolysis of glycosidic linkage at low pH ≤ 3 resulting in viscosity dropping • $\kappa$ -C forms firm brittle gels with strong syneresis, unstable freeze-thaw stable, hysteresis 10–20 °C • Desulphatation by sulphatases • Complete functionality loss at high temperature and low pH	Vieble, Piculell, and Nilsson (1994); Nussinovitch (1997); Phillips and Williams (2009); Wang et al. (2005); Mikš, Valík, and Dodok (2011); Necas and Bartosíková (2013); Wustenberg (2015)



Alginic (Sodium alginic) Brown seaweed extract/ alginic acid derivatives Species include <i>Laminaria</i> <i>hyperborea</i> , <i>Macrocytis pyrifera</i>	<ul style="list-style-type: none"> <li>Opaque, yellowish aqueous solution, odorless</li> <li>Average molecular weight 32–200 kDa</li> <li>Gel formation in presence of <math>\text{Ca}^{2+}</math> ions</li> <li>Medium dosage level in foods (0.7%–2%), gelation range 1%–2%</li> <li>Stable at neutral pH range (5–9)</li> <li>Exhibit pseudoplasticity (shear thinning) property due to parallel arrangement of linear molecule chain</li> </ul>	<p>Thermo-irreversible gelation</p> <p>Gels formed on the addition of polyvalent cations notably calcium ions at low pH (&lt; 4).</p> <p>Molecules cross-linked by the polyvalent ions.</p> <p>Guluronic acid residues give a buckled conformation providing an effective binding site for the cations (egg box model)</p>	<ul style="list-style-type: none"> <li>Biodegradable</li> <li>Biocompatible</li> <li>Non-antigenic</li> <li>Cheating property</li> <li>High gel strength</li> <li>High thickening effect</li> <li>High stability during cooking, baking, cooling, freezing</li> <li>Crystallization control: Freeze thaw stable gels is possible</li> <li>Heat stable gels</li> <li>High impact of electrolytes especially with <math>\text{Ca}^{2+}</math> ions give better strength</li> <li>Forms stable gels at low and high temperature and at low pH</li> </ul>	Liu et al. (2003); Mikus et al. (2011); Wustenberg (2015)
				• $\text{pH} < 5$ , viscosity decreases over storage time
				• Exhibit syneresis over storage time
				• Decomposition by acid ( $\text{pH} < 5$ ), alkaline ( $\text{pH} > 9$ ), free radical oxidation, enzymes
				• Murphy (2000); Skora et al. (2007); Viturawong, Achayuthakan, and Suphanthanika (2008); Xiao (2013); Ismail, Irani, and Ahmad (2013); Wustenberg (2015); Gutierrez et al. (2015); Haroon et al. (2016)
				• Loss of viscosity on over-cooking
				• Not freeze thaw stable
				• Thickening upon storage and cooking
				• Absence of certain functional groups
				• Retrodegradation
Starch Seed reserve extract (germ and root) in potato, waxy maize, wheat, rice, tapioca	<ul style="list-style-type: none"> <li>Composed of two units:</li> <li>Anxylopectin (70%–80%) consisting 95% <math>\alpha</math>-(1→4) and 5% <math>\alpha</math>-(1→6) linkages</li> <li>Amylose (20%–30%) consisting (1→4)-linked <math>\alpha</math>-D-glucan</li> </ul>	<p>Turbid suspension</p> <p>Insoluble in cold water and soluble in hot water</p> <p>Swelling + gelling (at <math>T &gt; 60^\circ\text{C}</math>; formation of heat-stable gels</p> <p>No or low impact of electrolytes</p> <p>Dosage level in foods: 1%–5%</p>	<ul style="list-style-type: none"> <li>Above overlap concentration (<math>C^*</math>) of amylose, gel is formed on cooling due to the formation of micro-crystallites of amylose that resembles a polymer gel consisting of closely packed granules, with a thin layer of amylose gel as a kind of glue between the granules</li> <li>High film formation capability</li> <li>High gel strength during cooking, baking</li> <li>High stability during cooking, baking</li> </ul>	Kulicke et al. (1996); Alexander (1999); Sannino et al. (2009); Koocheki et al. (2009); Wustenberg (2015); Ali and Ahmed (2018)
				• Low cost
				• Non-toxicity
				• Biocompatible
				• Biodegradability
				• Bioadhesiveness
				• HPMC and MC:
				• Viscosity increases with temperature, no effect of pH and electrolytes
				• High emulsion stabilization
				• High film formation
Cellulose include modified cellulose derivatives: MC HPC HPMC MEC CMC	<p>Anhydro-glucosyl units joined with -<math>(1,4)</math> glycosidic bonds</p>	<p>CMC soluble in either cold water or hot water, shear thinning property</p>	<p>Thermo-reversible gelation</p> <p>L.M: Thermo-reversible gelation</p> <p>Gels formed in the presence of divalent cations, notably calcium at low pH (<math>3 \pm 4.5</math>) which cross link the galacturonic acid chains</p>	Oakenfull (1987); May (2000); Phillips and Williams (2009); Wustenberg (2015); Martau, Mihai, and Vodnar (2019)
				• Low viscosity hence not used as thickening agent
				• Poor moisture barrier
				• Low thermal stability
				• Limited usage; only works well with low moisture foods
Pectin	<p>Low Methoxy (LM)</p> <p>High Methoxy (HM) derived from the cell wall of higher terrestrial plants, fruits and vegetable peels</p>	<p>Partially esterified <math>\alpha</math>-(1,4)-D-galactouronic and mannuronic acid</p> <p>Sometimes, galactouronic acid is replaced by rhamnose, galactose and arabinose</p>	<p>Linear heteropolysaccharide</p> <p>Opaque, yellowish aqueous solution</p> <p>Soluble in water and insoluble in organic solvent</p>	<p>Low viscosity hence not used as thickening agent</p> <p>Poor moisture barrier</p> <p>Low thermal stability</p> <p>Limited usage; only works well with low moisture foods</p>

(continued)

Table 1. Continued.

Type of Hydrocolloid	Chemical Composition	Characteristics	Type of Gelation and Mechanism of Gelation	Merits	Limitations	References	
Guar gum Endosperm of seeds of the guar plant ( <i>Cyamopsis tetragonolobus</i> or cluster bean)	$\beta$ -D-mannose and $\alpha$ -D-galactose in molecular ratio 1.6:1	<ul style="list-style-type: none"> <li>In case of LMP, only soluble as Na and K salt</li> <li>Degree of esterification decide gelling characteristics</li> <li>Gel formation in presence of <math>\text{Ca}^{2+}</math></li> <li>Gelling agent concentration for LM: 0.1%–4% wt/wt</li> <li>Gelling concentration for HM: 2%–4% wt/wt</li> <li>Neutral polysaccharide appearance in aqueous solution</li> <li>Good solubility in cold water</li> <li>Viscosity increases at low concentration</li> <li>Exhibit pseudoplasticity</li> <li>&gt;0.5% concentration</li> <li>Commonly used dosage</li> <li>concentration: 0.1%–0.5%</li> </ul>	<ul style="list-style-type: none"> <li>HM: Thermo-irreversible gelation</li> <li>Gels are formed at high solid levels and low pH range</li> </ul>	<ul style="list-style-type: none"> <li>Nontoxic</li> <li>Bioavailability</li> <li>Low production cost</li> </ul>	<ul style="list-style-type: none"> <li>High thickening effect</li> <li>Upon cooling, molecules undergoes a coil helix transition followed by aggregation of helices in the presence of salts</li> <li>No effect of monovalent cations</li> <li>Addition of di and trivalent cations leads to increase viscosity</li> <li>High crystallization control power</li> <li>Prevent syneresis</li> <li>Texture control</li> <li>Wider branching results in easy hydration, higher water activity and stability in pH 2–10</li> </ul>	<ul style="list-style-type: none"> <li>Addition of polyols reduce viscosity</li> <li>No gelation property (gelation occurs only with borate ions)</li> <li>Decomposition occurs with heating at temperature &gt; 90°C and pH 3.5, strong acids or alkali, strong oxidizing agent, specific enzymes</li> <li>Irreversible viscosity loss at &gt;90 °C</li> </ul>	<ul style="list-style-type: none"> <li>Robinson, Ross-Murphy, and Morris (1982); Wielinga and Maehall (2000); Turabi, Sumnu, and Sahin (2008); Achayuthakan and Suphanthanarka (2008); Koocheki et al. (2009); Sannino et al. (2009); Mikus et al. (2011); Wustenber (2015)</li> </ul>
Tara gum Endosperm of seed of tara tree ( <i>Caesalpinia spinosa</i> )	D-mannose + galactose	<ul style="list-style-type: none"> <li>Neutral polysaccharide</li> <li>White to yellowish powder</li> <li>Similar properties to guar gum and locust bean gum</li> <li>Partially soluble in cold water and completely soluble in hot water</li> <li>Intermediate acid stability</li> </ul>	<ul style="list-style-type: none"> <li>Non-gelling agent</li> </ul>	<ul style="list-style-type: none"> <li>Stable to high temperature</li> </ul>	<ul style="list-style-type: none"> <li>Unstable acid stability at pH &lt; 3.5</li> </ul>	<ul style="list-style-type: none"> <li>Wielinga and Maehall (2000); Turabi, Sumnu, and Sahin (2008); Koocheki et al. (2009); Wustenber (2015)</li> </ul>	
Locust bean gum Endosperm of seeds of carob tree ( <i>Ceratonia siliqua</i> )	(1,4) $\beta$ -D-mannose and (1,6) $\alpha$ -D-galactose in molecular ratio 3.5:1	<ul style="list-style-type: none"> <li>Neutral galactomannan polysaccharide</li> <li>Opaque, gray, cloudy Average molecular weight 310kDa</li> <li>Limited solubility</li> </ul>	<ul style="list-style-type: none"> <li>Thermo-irreversible gelation</li> <li>On cooling, polymannan chains associate following the coil-helix transition.</li> <li>Galactose deficient</li> </ul>	<ul style="list-style-type: none"> <li>High thickening effect</li> <li>No syneresis in gels with xanthan or <math>\kappa</math>-C</li> <li>High crystallization control</li> <li>Low impact of electrolytes</li> </ul>	<ul style="list-style-type: none"> <li>Decomposition occurs by heating at pH &lt; 3.5, strong acids or alkali, strong oxidizing agent, specific enzymes, high temperature</li> </ul>	<ul style="list-style-type: none"> <li>Richardson, Willmer, and Foster (1998); Ramirez et al. (2002); Dakia et al. (2008); Turabi, Sumnu, and Sahin (2008); Koocheki et al. (2009); Mikus et al. (2009); Mikuš et al.</li> </ul>	

Stable in pH range 3–11 Exhibit pseudoplasticity Dosage range in foods 0.1%–2%, mostly used 0.2%–0.5% Higher mannose to galactose ratio increases viscosity Commonly used dosage concentration: 0.1%–0.5%	regions are involved in the association	High viscosity after heating and cooling Low viscosity in cold water	Gelation occurs only with xanthan Low gel transparency No film formation	(2011); Wustenberg (2015)	
Tamarind gum Extracted from endosperm of tamarind tree ( <i>Tamarindus indica</i> )	D-glucose + D-galactose + D-xylose in molecular ratio of 3:1:2 Low amount of L-arabinose	Neutral branched polysaccharide Regarded as galactoxylogucan Creamy white powder, odorless, tasteless Warm water soluble to produce gels with broad pH tolerance Also forms gels in acidic, neutral pH, sugar Average molecular weight 50–115 kDa Exhibit pseudoplastic behavior Approved FDA as safe food additive for oral consumption Can be used as a substitute of fruit pectin	Non-gelling agent Stable at wide pH range Do not show syneresis Maximum gel strength with 1% gum seed + 50% sugar at pH 2.8 Biodegradable Biocompatible Non-carcinogenic Nonirritant hydrocolloid Good film forming property with higher flexibility Good tensile strength High thermal stability Excellent stability at high salt (20%) Good stability to heat at low temperature (65 °C) over pH range 3 to 7	Form stable gels with sugar concentration 0.5%–1.5% • Not digested by human digestive enzymes	Glicksman (1986); Wustenberg (2015); Nayak and Pal (2017)
Konjac Mannan Obtained from tubers of <i>Amorphophallus</i>	$\beta(1 \rightarrow 4)$ -linked D-glucopyranose and $\beta$ -D-mannopyranose sugars in ratio of 1:1.6 Small amount of acetyl group is also present in side chain	Water soluble polysaccharide Substitute of gelatin At high pH, it changes to gel	Thermally irreversible gelation occur by alkaline and borate cross-linking. Synergistically interact with other hydrocolloids and forms reversible gel. Geling can occur by alkaline processing, borate cross-linking, polymer compounding, high voltage electric field, metal ion cross-linking after modification.	Viscosity decreases with decreases in pH • Cheap • Non-toxic • Biodegradable • Biocompatible • Improves suspension effect • Increases strength and toughness • Good film forming ability • Good gelation power	Phillips and Williams (2009); Yang et al. (2017)

(continued)

Table 1. Continued.

Type of Hydrocolloid	Chemical Composition	Characteristics	Type of Gelation and Mechanism of Gelation	Merits	Limitations	References
Gum arabic (Acacia gum) Obtained from <i>Acacia</i> <i>Senegal</i> or <i>Acacia seyal</i> tree	D-galactose, L-arabinose, L-tharmanose and D-glucuronic acid in molecular ratio of 5:3:1:1	Highly branched neutral to slightly acidic arabinogalactan polysaccharide Average molecular weight about 350 kDa Water soluble up to 50% wt/wt Grayish-white to yellowish appearance Shear thinning at low shear rate (<10/sec); Newtonian behavior above (>100/sec shear rate) Dosage level in food >5%	Rarely used as gelling agent Resistant to hydrolysis in medium acidic system (4–9), thermal and enzymes due to highly branched structure Exhibit good emulsification property	Heat and enzyme stable High film forming ability Resistant to hydrolysis in medium acidic system (4–9, pH < 9)	Low viscosity gum in cold water, also further decreases on heating Decomposed by strong acids or alkali (4 > pH < 9) Precipitation and viscosity reduction on presence of electrolytes (e.g., CaCl <sub>2</sub> ) Low crystallization control Viscosity decreases on ageing thus use preservatives like benzoic acid (0.2%) Prolonged exposure to UV also reduces viscosity	Mohe and Rao (1999); Ravi and Bhattacharya (2004); Sopade et al. (2008); Phillips and Williams (2009); Mikúš et al. (2011); Wustenber (2015)
Gum karaya Obtained from species of <i>Sterculia</i> or <i>Cochlospermum</i>	Building blocks are 55%–60% neutral monosaccharide units (D-galactose and L-rhamnose), 37%–40% acid residues (D-galacturonic and L-glucuronic acid) and 8% acetyl groups Main chain is $\alpha$ -L-rhamnopyranose and $\alpha$ -D-galacturonic acid which is joined to side chain by $\gamma$ -(1,2)- $\beta$ -D-galactose or $\alpha$ -(1,3)- $\beta$ -D-glucuronic acid	Acetylated glycano rhamnogalacto-uritan polysaccharide Average molecular weight is about 9.5 MDa up to 16MDa Acetic taste and odor Light gray to pinkish gray powder Forms viscous colloidal dispersion at low concentration (<0.02% in cold water, 0.06% in hot water) Forms thick gel like paste at concentration 3%–5%	Rarely used as gelling agent Shows true plasticity Compatible with most gums Good acid stability Good water binding ability Forms colloidal dispersion at high concentration (up to 5%)	Exhibit spreadable quality Shows true plasticity Compatible with most gums Good acid stability Good water binding ability Subjected to microbial attack Lose viscosity with strong electrolytes Poorly soluble at low concentration (<0.02%)	Viscosity decreases with ageing Viscosity decreases at pH 2–5 and >11 Insoluble in higher alcohol concentration Subjected to microbial attack Lose viscosity with strong electrolytes Poorly soluble at low concentration (<0.02%)	Le Cerf, Irinei, and Muller (1990); Weiping et al. (2000); Mikúš et al. (2011); Lujan-Medina et al. (2013); Wustenber (2015)
Gum ghatti Extracted from bark of tree <i>Anogeissus latifolia</i>	L-arabinose + D-galactose + D-mannose + D-xylose + D-glucoronic acid in molecular ratio of 10:6:2:1:2	Maximum viscosity at pH 5–7 Acidic polysaccharide Average molecular weight is about 270 kDa 80%–90% gum soluble in water Mild taste and odorless Color vary from tawny to dark brown	Presence of two fractions in the gum ghatti: 1. one soluble in cold water other forming a dispersible gel	Act as a buffer Good emulsifying property	Addition of Na <sup>+</sup> salts decreases viscosity Viscosity loss above pH < 3 and pH > 11	Deshmukh et al. (2012); Wustenber (2015)

				(continued)
Forms colloidal dispersion in hot or cold water Stable between pH 3–11	Mixture of 2 component: Tragacanthic acid (60%–70%) + Tragacanthin (30%–40%)	White or off-white powders Acidic, highly branched hydrophilic polysaccharide Average molecular weight is about 840 kDa Soluble in hot or cold water Tragacanthin forms colloidal solution whereas Tragacanthic acid forms gel Gelation improved by $\text{Ca}^{2+}$ Exhibit pseudoplasticity at concentration 0.5%	Gelation properties are improved by $\text{Ca}^{2+}$ ions Stable over wide pH range 2.5–10, maximum at 4–8 Effective bifunctional emulsifier lowering interfacial tension between oil and water Forms highly viscous dispersion at 1% concentration Resistant to hydrolysis and mechanical straining Biocompatible Nontoxic	Prolonged heating causes permanent viscosity loss influenced by pH •
Xanthan gum Fermentation of glucose and sucrose by <i>Xanthomonas campestris</i>	Glucose + Mannose + Glucuronic acid in molecular ratio of 3:3:2	Long chain polysaccharide Average molecular weight: 2000 kDa Fast hydrating water soluble hydrocolloid Opaque appearance of aqueous solution Dosage level in foods 0.05%–0.5% Exhibit pseudoplasticity	Thermo-reversible gelation Upon cooling, xanthan and polymannan chains associate followed by coil-helix transition •	Viscosity decrease of heating Unstable in extreme acidic medium and enzymes Low gel transparency •
Curdlan Obtained from nonpathogenic bacteria <i>Agrobacterium biovar</i> and mutants of <i>Alcaligenes faecalis</i> var. <i>myxogenes</i>	Linear $\beta(1 \rightarrow 3)$ -glucan	Odorless white powder Insoluble in water up to 54 °C. Above this temp, it begins to swell and forms strong elastic gels Gel strength is between agar and gelatin Soluble in aqueous alkaline solution Gel strength increases with temperature Forms water insoluble films with strength	Curdlan form two types of heat induced gels: 1. Low-set gel: Thermo-reversible gelation in which cross-linking between curdian micelles, which are occupied by molecules of single-helix is caused through hydrogen bonding. This gelation is independent of concentration •	Exhibit syneresis that strongly depends on storage temperature •

Table 1. Continued.

Type of Hydrocolloid	Chemical Composition	Characteristics	Type of Gelation and Mechanism of Gelation	Merits	Limitations	References
Dextran Fermentation of sucrose by enzymes of <i>Leuconostoc</i> or <i>Streptococcus</i>	Composed of glucose units belong to homoglycans	between cellulose and amylose	2. High-set gel: Thermo-reversible gelation in which cross-linking between curdian micelles which are occupied by molecules of multiple-chain helix or triple-stranded helix forming a three-dimensional network caused through hydrophobic interactions. This is concentration dependent gelation	Native dextran possess high degree of polydispersity High solubility	• Highly branched dextran can cause allergies in humans Oxidized in alkaline solution Promotes low viscosity in solutions • Higher molecular weight dextran solutions possess slight pseudoplasticity at concentrations >1.5% wt/wt • Addition of salt ions will decrease gelation by both decreasing the hydrophilic interactions and increasing the hydrophobic ones between dextran molecules	Phillips and Williams (2009); Padmanabhan et al. (2003); Wustenber (2015)
Gellan gum Produced through fermentation by the microorganism <i>Sphingomonas elodea</i>	D-glucose, L-rhamnose, and D-galacturonic acid in a molecular ratio of 1.5:1:1		Linear, anionic heteropolysaccharide Dispersible in cold water and fully soluble in hot water Forms gels at low ion concentration Available in substituted and unsubstituted form Substituted form soft and elastic gels while	Thermo-reversible gelation In aqueous solution at high temperatures, gellan gum are in a disordered single coiled state. Cooling of gellan sol promotes the formation of double helix which stabilizes by internal hydrogen bonding Coil-helix conformational transition occurs at 30	• Rapid setting Sparkling clarity Goof flavor release Decrystallized gellan gum improve moisture retention, storage stability and reduce syneresis • Exhibit high modulus of elasticity thus imparting suspensive property	Chandrasekaran and Radha (1995); Sworn (2000); Valli and Miskiel (2001); Horinaka et al. (2004); Wustenber (2015)

unsubstituted form hard and brittle gels Gelling concentration 0.5%–1.5% Low level is used Exhibit pseudoplasticity at low concentration Stronger gels formed in presence of appropriate ions ( $\text{Na}^+$ or $\text{Ca}^{2+}$ )	to 50 °C. After this transition, the double helixes associate in the presence of cations to form junction zones, which aggregates and leads to the formation of three-dimensional gel network	Blending of high and low acyl gellan gum create greater flexibility	Poppe (1992); Tosh et al. (2003); Renard, Lavenant-Gougeon, et al. (2006); Wustenberg (2015); Ali and Ahmed (2018)		
Gelatin	<p>Gelling concentration 1%–5% wt/wt</p> <p>Low gelation temperature 20–30 °C</p> <p>Dosage concentration in foods 0.1% for effective functional properties</p>	<ul style="list-style-type: none"> <li>Thermo-reversible gelation</li> <li>Gelation occurs by the partial molecules reassemble into a network of triple helices, forming a thermo-reversible viscoelastic gel upon cooling</li> <li>In the first step, a polypeptide chain takes an orientation to induce a reactive site.</li> <li>Later, condensation of two other chains near the reactive site occur giving rise to triple helix formation</li> </ul>	<ul style="list-style-type: none"> <li>High water binding capacity</li> <li>Protective colloidal formation</li> <li>Nontoxic</li> <li>Non-allergenic</li> <li>GRAS status</li> <li>Excellent biocompatibility</li> <li>High quality</li> <li>Controllable physical parameter</li> <li>Exhibit smooth texture</li> <li>High clarity</li> <li>Low immunogenicity and low cytotoxicity</li> <li>Biodegradable</li> <li>Flexible, reversible and transparent gels</li> </ul>	<ul style="list-style-type: none"> <li>Low mechanical and thermal stability</li> </ul>	Cayot and Lorient (1997); Phillips and Williams (2009); Gunasekaran, Ko, and Xiao (2007); Jong, Klok, and Velde (2009)
Whey protein By-product of cheese	<p>15% whey protein milk</p> <p>Native globular conformation</p> <p>Insoluble at isoelectric pH (4.5)</p> <p>Soluble at low ionic strength (&gt;0.025 M) over the entire pH range encountered in food applications</p> <p>Minimum viscosity at isoelectric point</p> <p>Second most abundant polymer after cellulose</p>	<ul style="list-style-type: none"> <li><math>\alpha</math>-lactalbumin, <math>\beta</math>-lactoglobulin, and bovine serum albumin are principle components</li> <li>Denaturation (unfolding) of native proteins</li> <li>Aggregation of unfolded molecules which is formed in presence of salts</li> <li>Strand formation from aggregates,</li> <li>Association of strands into a network</li> <li>Thermal reversible gelation</li> </ul>	<ul style="list-style-type: none"> <li>Good pH-sensitive swelling capacity</li> <li>Resistance to coalescence</li> <li>Increase in pH (6–10) slightly increase in viscosity</li> </ul>	<ul style="list-style-type: none"> <li>Brittle in nature and hence limited industrial applications</li> <li>Highly influenced by temperature and its protein content</li> <li>Heat sensible gels; denature on heating at ~70 °C</li> <li>Solubility decreases at high ion concentration causing salting out</li> </ul>	Cayot and Lorient (1997); Phillips and Williams (2009); Gunasekaran, Ko, and Xiao (2007); Jong, Klok, and Velde (2009)
Chitosan	<p><math>\beta</math>-(1→4)-D-glucosamine and N-acetyl-D-glucosamine units formed by partial deacetylation of chitin</p> <p>Exoskeletons, peritrophic membranes and cocoons of insects, mollusks, fungal walls such as Mucor</p>	<p>Linear water soluble polycation hydrocolloid</p> <p>Insoluble in organic solvents, high concentrated acids and alkaline solution</p>	<ul style="list-style-type: none"> <li>Biodegradable</li> <li>Biocompatible</li> <li>Nontoxic</li> <li>Non-immunogenic</li> <li>Exhibit antimicrobial, permeability and solubility property</li> <li>Decreases swelling and improves mechanical property</li> </ul>	<ul style="list-style-type: none"> <li>Exhibit pH sensitive behavior as weak gels due large amounts of amino groups</li> <li>Poor solubility because of high crystallinity of chitin</li> </ul>	Phillips and Williams (2009); Martau, Mihaï, and Vodnar (2019)

(continued)

Table 1. Continued.

Type of Hydrocolloid	Chemical Composition	Characteristics	Type of Gelation and Mechanism of Gelation	Merits	Limitations	References
		<ul style="list-style-type: none"> <li>• Soluble in aqueous acidic and alkaline solution</li> <li>• Positive charged polysaccharides in acidic system</li> <li>• Insoluble at higher pH range while readily dissolve at low pH</li> </ul>				

evaluated. On the basis of energy of thixotropy, combination of oat starch + xanthan gum has better thickening properties than starch and xanthan gum. This is due to the fact that both the components (starch + xanthan gum) are anionic polysaccharides, therefore, thermodynamically incompatible for efficient intermolecular bonding necessary for thickening. On the other hand, oat starch and oat hydrolysate also resulted in poor thickening due to efficient intermolecular bonding could not be established between high molecular oat starch and low molecular maltodextrins of oat hydrolysate.

Modified starch, xanthan gum, guar gum, locust bean gum, gum arabic, gum karaya, gum tragacanth, cellulose derivatives are some of the hydrocolloids used as thickeners in soups, gravies, salad dressing, sauces and toppings (Shah and Bhattacharya 2010; Krystyjan et al. 2012).

### Gelling property

Gelation is a process of phase transformation (sol or high molecular aqueous dispersion to gel, or colloidal) that has lost its flow ability due to inter-molecular interactions between sol particles, which form three dimensional stable structure resistant to external stresses (Yuryev, Tomasik, and Bertoft 2007).

Gel is a visco-elastic system with greater “storage modulus” ( $G'$ ) than “loss modulus” ( $G''$ ) (de Vries 2004). Although aqueous dispersions are thickened by all hydrocolloids, but only a relatively small number of hydrocolloids such as agar, carrageenan, alginate, pectin, gelatin, gellan gum, modified starch, MC and HPMC form gels by physically associating polymer chains via hydrophobic association, hydrogen bonding and cation mediated cross-linking (Phillips and Williams 2009). Hydrocolloid polysaccharide gels usually consist of 1% polymer and 99% water, achieving firm and stable structure (Yuryev et al. 2007).

Hydrocolloid gel formed by entwining and cross-linking polymer chains with solvent in the interstices into a three-dimensional network (Burey et al. 2008). Gelling can proceed under the influence of thermal (agar), chemical (alginates), or thermo-chemical factors (carrageenan, high methyl pectin) (Glicksman 1982). On this basis, there are three mechanisms of hydrocolloid gelation, namely: Ionotropic gelation, cold-set gelation, and heat-set gelation (Burey et al. 2008). The hydrocolloid gelling process is also concerned with interactions between polymer-polymer, polymer-solvent, polymer-electrolyte ions (e.g.,  $\text{Ca}^{2+}$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ) and is mostly based on double helices formation from randomly coiled chains suspended in solution.

Hydrocolloid gelation includes a hierarchy of associated regions known as “junction zones,” created by aggregation of the three dimensional gel network of two or more polymer chains (Shah and Bhattacharya 2010). Gel texture and thermal activity of gel are related directly to the number of molecules constituting junction zones (Viturawong, Achayuthakan, and Suphantharika 2008; Stewart et al. 2014). More the number of molecules in the junction zone, more rigid will be the gel e.g., alginate gels do not melt on boiling due to the “egg box” junction while gelatin melts at a much

**Table 2.** Applications of natural edible hydrocolloids in food and pharmaceutical industry.

Hydrocolloid	Functions of hydrocolloid	Food and beverages	Pharmaceutical and biotechnology	References
Agar	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Emulsion/Foam stabilizer</li> <li>• Fining agent</li> <li>• Preparation of culture media in microbiology</li> <li>• Film former</li> <li>• Encapsulating agent</li> </ul>	Bakery products, pudding, jelly, canned food, jam, dessert, ice-cream, sauces, wines, canned meat, fish and poultry products, laxative, vegetarian gelatin substitute in jellies and Japanese desserts	Impression materials in dentistry, intestinal regulator, excipient in pills, microsphere and beads, growth media, gel electrophoresis, bulk laxative, , surgical lubricant	Armisen, Galatas, and Hispanagar (2000); Stanley (2006); Khalil et al. (2018), John, Declan, and James (2006)
Carrageenan	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Thickener</li> <li>• Fining agent</li> <li>• Stabilizer</li> <li>• Emulsifier</li> <li>• Film forming agent</li> <li>• Binding agent</li> <li>• Crystallization inhibitor</li> <li>• Suspending agent</li> <li>• Swelling agent</li> <li>• Syneresis inhibitor</li> <li>• Encapsulating agent</li> <li>• Pore former</li> <li>• Tensile strength enhancer</li> <li>• Color stability</li> <li>• Fat replacer</li> <li>• Gelatinization</li> </ul>	Immobilization of enzymes, cells, industrial vinegar production, ethanol production, fermented milk, biodegradable packaging film, flavored milk, infant formulas, cream filling, dairy desserts like pudding and milk shakes	Tetracycline and chlorotetracycline production, semi-synthetic antibiotic production, D-aspartic acid production, biomedical application, drug delivery system, regenerative medicine and tissue engineering	Langendorff et al. (2000); Puvanenthiran et al. (2003), de Vries (2004); Verbeken, Thas, and Dewettinck (2004); Soukoulis, Chandrinos, and Tzia (2008); Khalil et al. (2018)
Alginate	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Coating agent</li> <li>• Encapsulating agent</li> <li>• Thickening agent</li> <li>• Emulsifier/Foam stabilizer</li> <li>• Adhesive agent</li> <li>• Cryo-protective agent</li> </ul>	Thickeners and stabilizer in dairy products drinks, ice-cream, jelly, pie and pastry filling, dessert gels, instant pudding, restructured foods, cold prepared bakery cream, flavors and probiotics encapsulation and functional food oil, fruit jelly and pudding, beer frozen products, artificial mozzarella	Dental impression, wound dressing, medicine for rheumatoid arthritis, additives in dehydrated products, antacid, prosthetic devices, biodegradable sutures, matrices to drug delivery system, tissue engineering	Guarda et al. (2004); Yanes, Durán, and Costell (2002); Madziva, Kailasapathy, and Phillips (2005); Gómez et al. (2007); Pelkman et al. (2007); Ali and Ahmed (2018), Correa-Filho, Mold ~ Ao-Martins, and Alves (2019)
Pectin	<ul style="list-style-type: none"> <li>• LMP and HMP: gelling agent</li> <li>• Thickener</li> <li>• Emulsifier</li> <li>• pH buffering agent</li> <li>• Coating agent</li> <li>• Encapsulating agent</li> <li>• Gelling agent</li> <li>• Thickener</li> <li>• Fat replacer</li> <li>• Film former</li> <li>• Adhesive agent</li> <li>• Whipping agent</li> </ul>	Jam, jelly, marmalade, jujubes, yogurt, coating material for fruits and vegetables preservation	Oral, colon, transdermal drug delivery system, wound dressing, and tissue engineering	Oakenfull (1987); Phillips and Williams (2009); Deshmukh and Aminabhavi (2014); Martau, Mihai, and Vodnar (2019)
Starch	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Thickener</li> <li>• Adhesive agent</li> <li>• Film former</li> <li>• Encapsulating agent</li> <li>• Molding agent</li> <li>• Whipping agent</li> </ul>	Food preservation like coating, thickening of soups, gravies	Wounddressing/antibacterial, controlled drug delivery, tissue engineering	Xiao (2013); Ismail, Irani, and Ahmad (2013); Kennedy et al. (2011); Sadeghi and Soleimani (2012); Hassan et al. (2018)
Cellulose	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Stabilizer</li> <li>• Thickener</li> <li>• Binding agent</li> </ul>	Packaging, binding and shaping of vegetable products, salad dressings and deserts	Dermal and transdermal drug delivery systems	Murray (2000); Phillips and Williams (2009); Ali and Ahmed (2018);
Guar gum	<ul style="list-style-type: none"> <li>• Thickener and Binder</li> <li>• Emulsifier/Foam stabilizer</li> <li>• Crystallization inhibitor</li> <li>• Texture controller</li> <li>• Syneresis inhibitor</li> <li>• Processing aid in canned foods</li> <li>• Clouding agent</li> <li>• Solid suspending agent</li> <li>• Fat replacer</li> <li>• Gelling agent</li> <li>• Surface tension reducer</li> </ul>	In ice-cream, dairy desserts, soups, sauces, meat and bakery products, pastry fillings, yogurt, liquid cheese products and sweet desserts	Drug delivery system, cross-linked microspheres, laxative	Richardson, Willmer, and Foster (1998); Wielinga and Maehall (2000); Cui, Ikeda, and Eskin (2007); Turabi, Sumnu, and Sahin (2008); Koocheki et al. (2009); Lujan-Medina et al. (2013); Deshmukh and Aminabhavi (2014)

(continued)

**Table 2.** Continued.

Hydrocolloid	Functions of hydrocolloid	Food and beverages	Pharmaceutical and biotechnology	References
Locust bean gum	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Gelling agent</li> <li>• Stabilizer</li> <li>• Suspension agent</li> <li>• Water linker</li> </ul>	Pie and fruit fillings, cookies, meringues, frozen candies, canned fish, meat and poultry, dairy products, ketchup, fruit juices, pudding powder, cake batter	Drug delivery system, hydrogels	Wielinga and Maehall (2000); Turabi, Sumnu, and Sahin (2008); Koocheki et al. (2009); Banerjee and Bhattacharya (2012); Lujan-Medina et al. (2013); Deshmukh and Aminabhavi (2014)
Tara gum	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Stabilizer</li> </ul>	Dairy products, ketchup, fruit juices, pudding powder, cake batter	Use as an intermediate in pharmaceutical as controlled release carrier	Wielinga and Maehall (2000); Turabi, Sumnu, and Sahin (2008); Koocheki et al. (2009); Wustenberg (2015)
Tamarind gum	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Stabilizer</li> </ul>	Jams, mayonnaise, ice-creams	Nasal drug delivery, mucoadhesive agent, hydrogels	Phillips and Williams (2009); Wustenberg (2015); Datta and Bandyopadhyay (2006)
Konjac Mannan	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Water binding agent</li> <li>• Gelling agent</li> <li>• Texturizing agent</li> <li>• Fat replacer</li> </ul>	Jellies, noodles and desserts, fat free and low fat meat products, low fat and skimmed yogurt, ice-cream	Drug carrier, tablet excipients, controlled release beads, tissue scaffold	Takigami (2000); Phillips and Williams (2009); Lujan-Medina et al. (2013); Yang et al. (2017)
Xanthan gum	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Emulsifier/Foam stabilizer</li> <li>• Suspending agent</li> <li>• Clouding agent</li> <li>• Texture modifier</li> </ul>	Ketchup, soup and gravies, instant beverages, desserts, toppings and fillings	Buccal drug delivery, tooth paste and ointments	Urlacher and Dalbe (1992); Santos et al. (2005); Vendruscolo et al. (2005), Ganesh et al. (2011); Lujan-Medina et al. (2013)
Curdlan	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Thickening and binding agent</li> <li>• Edible coating</li> </ul>	Jellies, desserts and confectionery products, can be used as thickener and binder in dietetic foods, edible coating for long life products, salad dressings and sauces, edible fibers, noodles	Drug delivery of bioactive molecules	Doublier and Cuvelier (2006); Sutherland (2007); Wustenberg (2015)
Dextran	<ul style="list-style-type: none"> <li>• Improved solubility</li> <li>• Film forming</li> <li>• Stabilizer</li> <li>• Carrier</li> </ul>	Improved solubility and flavor mixing in tea and coffee powders, protective coating materials	Used in medicine as a substitute for blood plasma, platelet aggregation inhibitor, freeze drying process, blood purification, X-ray contrast liquids, carriers for gel chromatography, as molecular sieves in chemical analysis, as tablet binder, and as protective colloid for cells to prevent freezing damage	Lujan-Medina et al. (2013); Wustenberg (2015)
Gellan gum	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Stabilizer</li> <li>• Film former</li> <li>• Binder</li> <li>• Clouding agent</li> </ul>	Stabilizes water-based gels such as desserts and drinking jellies, improves bake-stability, replaces gelatin in cultured dairy products such as yogurt and sour cream in vegan, reduces cloud and pulp settling in beverages, preparation of low-calorie jams, no-fat salad dressing	Mucoadhesive drug delivery system	Phillips and Williams (2009); Lujan-Medina et al. (2013)
Gum arabic (Acacia gum)	<ul style="list-style-type: none"> <li>• Emulsifier</li> <li>• Coating agent</li> <li>• Gelling agent</li> <li>• Texture modifier</li> <li>• Stabilizer</li> </ul>	Fruit juice beverages, soft drinks, ketchup, caramels, candy gels, meringues, jellies, coating of fruits and vegetables, hard gummy candies, chocolate candies and chewing gums	Controlled and osmotic drug delivery, binders in tablets	Mothe and Rao (1999); Buffo, Reineccius, and Oehlert (2001); Ravi and Bhattacharya (2004); Sutherland (2007); Sopade et al. (2008); Deshmukh and Aminabhavi (2014)
Gum karaya	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Emulsifier</li> <li>• Adhesive</li> <li>• Suspending agent</li> </ul>	Brown sauce, toppings, fillings, ice-creams, candies, cream, beer, meringues	Dental adhesive, release of diltiazem, quetiapine fumarate, Aceclofenac, metformin, delivery of essential oil in patches	Le Cerf, Irinei, and Muller (1990); Weiping et al. (2000); Lujan-Medina et al. (2013); Wustenberg (2015)
Gum ghatti	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Emulsifier</li> <li>• Binder</li> <li>• Suspending agent</li> </ul>	Butter containing table sirups, confectionery	Tablets excipient, hydrogels, preparation of powdered form oil soluble vitamins	Phillips and Williams (2009); Wustenberg (2015)

(continued)

**Table 2.** Continued.

Hydrocolloid	Functions of hydrocolloid	Food and beverages	Pharmaceutical and biotechnology	References
Gum tragacanth	<ul style="list-style-type: none"> <li>• Thickener</li> <li>• Bi-functional emulsifier</li> <li>• Stabilizer</li> </ul>	Salad dressings, bakery emulsions, fruit beverages, sauces confectionary icings, dressings	Demulcent, emollient in cosmetics	Aspinall and Bail Lie (1963); Alexander (1999); Weiping et al. (2000); Deshmukh and Aminabhavi (2014); Wustenberg (2015)
Gelatin	<ul style="list-style-type: none"> <li>• Gelling agent</li> <li>• Clarifying agent</li> <li>• Encapsulating agent</li> <li>• Fat replacer</li> <li>• Foaming agent</li> <li>• Texturing agent</li> <li>• Water binding agent</li> <li>• Emulsification</li> <li>• Adhesive agent</li> <li>• Thickening agent</li> </ul>	Low fat and reduced calorie product, confectionery products like table jellies, dairy products, meat products, jam, yogurt, cream cheese and margarine	Controlled and targeted drug delivery, bioresorbable cell/ drug carrier matrix, 3-D culturing platform for capture and release of cell, regeneration of damaged tissue	Ward and Courts (1977); Oakenfull (1987); Einerson, Stevens, and Kao (2003); Schrieber and Gareis (2007); Anirudhan and Mohan (2014); Ullm et al. (2014); Truong et al. (2015)
Whey protein	<ul style="list-style-type: none"> <li>• Fat replacer</li> <li>• Thickener</li> <li>• Gelling agent</li> </ul>	Nutritional beverages, bars and yogurts reduced fat cheeses	Substrate for in vitro cell culture	Aguilera and Rademacher (2004); Gilbert et al. (2005)
Chitosan	<ul style="list-style-type: none"> <li>• Coating agent</li> <li>• Adhesive</li> <li>• Encapsulating agent</li> </ul>	Food packaging, antimicrobial films and coatings in fresh fruits and vegetables	Wound dressing, Scar prevention wound healing, microcapsules, drug delivery hydrogels, gene delivery, and tissue engineering scaffolds, in vivo testing	Anjum et al. (2016); Martua et al. (2019)

lower temperature as junction zones are bound by weak hydrogen bonds (Saha and Bhattacharya 2010; Xu et al. 2013).

### Emulsification and surface activity

Another important hydrocolloid feature is emulsification. In most hydrocolloids (polysaccharides), only a few act as emulsifiers while others act only as stabilizers. Emulsion is a mixture of two immiscible fluids in which one phase is continuous and the other is dispersed phase that facilitates emulsion formation and conserves a uniform texture by reducing interfacial tension between the two phases. Another important phenomena is the stabilization of the emulsion system which confers long-term emulsion stability (Dickinson 2003). Further, additional hydrocolloids often modify the rheology of emulsion and prevent creaming. Sugar beet pectin and gum arabic are polysaccharide-based hydrocolloids that contain complex hydrophobic protein components that chemically integrated with hydrophobic groups (e.g., octenyl succinic anhydride modified starches, hydroxypropyl methyl cellulose and hydroxypropyl cellulose) that may aid in emulsion formation/emulsion stabilization.

On the other hand, hydrocolloid surface activity behavior is either due to the presence of protein fractions which are physically or covalently or by the existence of non-polar functional groups bound to polysaccharides. Food hydrocolloids exhibit surface active characteristics primarily due to their amphiphilic nature which results in rapid adsorption by oil–water or gas (e.g., air, nitrogen or carbon dioxide) – water interface to form emulsions (oil-in-water) and foams, respectively. A good example of surface active hydrocolloids is non-micellar caseins such as sodium caseinate and whey protein found in whey protein concentrates (McSweeney 2008).

### Fat replacers

Modern lifestyle, growing awareness of balanced lifestyle and new processing technologies have led to a rapid increase in ready-to-use foods and creation of novel foods which is low in fat and high in fiber. Fats and oils are calorie dense materials which can be substituted with “structured water” to provide balanced and high quality reduced-calorie diet along with excellent eating quality. Many hydrocolloids based food products have been developed specifically for use as fat replacers in food. As a result, the demand for hydrocolloids has consequently increased for example, “Light” mayonnaise contains guar gum and xanthan gum is used as fat replacers to enhance viscosity while in Italian dressing, xanthan gum is used as a thickener.

### Encapsulation

Encapsulation consists of shielding active substances (in the liquid, solid or gas state) in a wall membrane (shell/coating) from the surrounding environment to obtain products with spherical form and micrometric size (Dubey 2009). Choice of encapsulation techniques for a particular process will depend on the size, biocompatibility and biodegradability of micro-particles needed, the physico-chemical properties of core and coating, the micro-particles application, the proposed mechanism for encapsulation.

Hydrocolloids are most widely used as an enclosure shell due to its edible, biodegradable nature and can form an obstacle between the core and its surroundings (Nedovic et al. 2011). Due to this, encapsulation technology is used for the following reasons:

- To protect sensitive bioactive compounds against inactivation
- To avoid evaporation and degradation of volatile components

Probiotic sensitivity is one of the examples of encapsulation. Probiotics is a single or mixed cultures of live microorganisms that confer health benefits primarily related to gastro-intestinal diseases to the host but it is difficult to preserve the viability of free probiotics during processing and storage due to environmental conditions such as oxygen, temperature, acidity etc (Ding and Shah 2009). Microencapsulation arose as an alternative method to protect probiotics which gives the microorganisms an encapsulated microenvironment and increases its stability. In order to encapsulate the probiotics, Shi et al. (2013) have created carrageenan-locust bean gum coated milk microspheres to enclose the probiotics species i.e., *Lactobacillus bulgaricus* and suggested that double layer structure of milk could improve the stability of *L. bulgaricus* in simulated gastro-intestinal conditions. Carrageenan was used as an encapsulating wall material for its gelling feature whose strength was synergistically enhanced by locust bean gum. Consequently, probiotic therapy or microbial intervention is commonly used in the development of microencapsulation.

Alginate has additionally been used as an exemplifying material because of easy handling, cheap, non-harmful nature and low capacity to assimilate water, simple to be controlled. It likewise incorporates additional highlights, for example, gelling, balancing out and thickening which have been of extraordinary enthusiasm to the food business (Burgain et al. 2011; Goh, Heng, and Chan 2012). Alginate based microcapsules, blends of alginates with milk or whey proteins and chitosan-coated alginates are utilized effectively for improving the reasonability and colonization of probiotics under gastric conditions (Shori 2017).

Other food hydrocolloids including protein-based hydrocolloids include gelatin, caseinate, whey protein and soy protein and polysaccharide-based hydrocolloid such as starch, maltodextrin and gum arabic) are broadly utilized in the exemplification to improve their solvency, steadiness, bio-active properties and bioavailability of flavor mixes, antimicrobials, antioxidants, bioactive compounds, colorants etc.

### **Adhesion**

For the food and pharmaceutical industry, hydrocolloids as adhesives are of great interest, since they are edible, nontoxic and hydrophilic material that increases their penetration into porous substances. Adhesion is another huge significant feature of hydrocolloid, known for its attractive forces, physical interactions and mechanical interlocking of holding materials together (Nussinovitch 2010). Countless hydrocolloids have been distinguished as adhesives like gum tragacanth, chitosan, gum ghatti, gum karaya, gelatin, dextran, gum arabic, CMC and HPMC (Phillips and Williams 2009; Nussinovitch 2010). For instance, gum arabic can be added to bread morsels to fastened adhesion in fish or chicken cutlets, meat steaks without wanting to cover with batter (Nussinovitch 2010).

In pharmaceutical sector, the utilization of hydrocolloids is widely used in bio-delivery system as muco-adhesives (Ono et al. 2000; Ludwig 2005; Lévesque and Shoichet 2006; Ahuja, Singh, and Kumar 2013). Another utilization of

hydrocolloid adhesive is chitosan-based adhesive films that bind strongly to the sheep intestine without any chemical modification. These types of adhesive film may likewise be utilized in tissue repairing (Hoemann et al. 2005; Barton et al. 2014; Shu et al. 2015; Deng et al. 2017).

### **Edible films or coating agent**

The edible films and coatings are defined as any kind of thin layer material that may be ingested with or without food by enrobing (coating or wrapping) different food products either by fortifying/replacing the natural layers of product with natural or chemical antioxidants, enzymes, antimicrobial agents or functional ingredients to prolong its shelf-life. Meat sausage is one of the most common examples of edible packaging in which casing is not removed for cooking and eating (Embuscado and Huber 2009).

For food surfaces, hydrocolloids are utilized to create edible films. For coating purpose, various gums and subordinates have been utilized such as alginate, carrageenan, cellulose and its derivatives, pectin, starch and its derivatives. Since these hydrocolloids are hydrophilic, their coatings have a moisture barrier that is minimal in nature. However, when used in gel form, the moisture loss may be postponed for a short duration, if the gel serves as a sacrificing agent, instead of becoming a moisture barrier. Moreover, hydrocolloid based films can provide effective protection against the oxidation of lipid and other susceptible food ingredients (Milani and Maleki 2012).

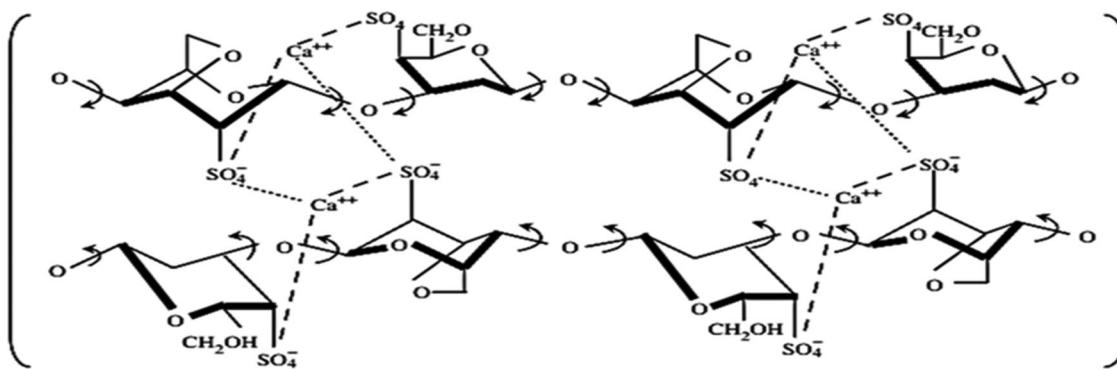
For food surfaces, hydrocolloids are utilized to create edible films. For covering reasons, various gums and subordinates have been utilized. These incorporate alginate, carrageenan, cellulose and its derivatives, gelatin and starch. Since these hydrocolloids are hydrophilic, their coatings have a minimal moisture barrier property. However, when use in gel structure, the loss of moisture misfortune might be delayed for a short duration, if the gel the gel serves as a sacrificing agent, instead of becoming a moisture barrier. Additionally, hydrocolloid based films can give viable assurance against the oxidation of lipid and other powerless food fixing (Milani and Maleki 2012).

### **Synergistic interactions of hydrocolloids**

Various parameters can influence synergistic interactions of hydrocolloid blends thus affecting the physical arrangement of junction zones within the network.

### **Ionic strength of counter ions: calcium chloride**

The type of external counter ions has a significant role in the hydrocolloid gelation process. Carrageenan, alginate or pectin are few examples that undergo ionic-induced gelation. External counter ions play an important role in the solution properties of carrageenan due to the reduction of the electrostatic repulsive forces of the polysaccharide (Takemesa and Nishinari 2004). In polysaccharide gels, ionic-induced gelation is most essential (Banerjee and Bhattacharya 2012).



**Figure 9.** Ca-bridges between iota-carrageenan molecules, Kara, Arda, and Pekcan (2007).

Gel formation in *l*-carrageenan involves helix formation in conjunction with gel inducing  $\text{Ca}^{2+}$  ions on cooling of hot solution, which not only aid in the formation of helices but also in aggregating associations between the helices to form junction zones (Imeson 2000). As a divalent cation, calcium ( $\text{Ca}^{2+}$ ) is capable of neutralizing and create intra-molecular bridges between the neighboring anhydro-D-galactose sulfate groups and carrageenan d-galactose residues, thus facilitating a tighter aggregation of the helices as shown in Figure 9. Owing to this  $\text{Ca}^{2+}$  intermolecular bridging, quaternary structure forms after cooling contributing to the mechanical and rheological properties of the resultant gels. Before gelation, the  $\text{Ca}^{2+}$  needs to be heated by  $60^\circ\text{C}$  to completely hydrate it (Thrimawithana et al. 2010). Addition of extra ions in the gelling system facilitates helix aggregation and enhances stability of the helix which is important for the gelation process (Burey et al. 2008).

In alginate gels,  $\text{Ca}^{2+}$  greatly increases viscosity by integrating the zig-zag structure of the GG-blocks (egg-box model) which gives rise to three-dimensional gel structure as shown in Figure 10.

Pectin gelation occurs when carboxylate groups are able to form coordination bonds with divalent cations framing an “egg-box” network as shown in Figure 11. However, concentration, the type of pectin (LM or HM pectin) as well as the cross-linking conditions are key parameters that emphatically influence pectin gelatin (Auriemma et al. 2013).

#### Solvent quality: presence of co-solute – sugar

The nature and presence of solvent markedly influences the interactions between polysaccharides thus affecting gel formation (Banerjee and Bhattacharya 2012). If the competition between inter-chain interactions and chain-solvent (water) interactions exists, the limitation of water molecules availability results in inter-chain interactions. It could be possible by an addition of low molecular weight compounds, e. g. sugars (Bayarri et al. 2006). Only concentrated sugar (co-solute) solution can form hydrogen bonds in the junction zones and therefore gelation takes place only in this type of solvent (Banerjee and Bhattacharya 2012).

The presence of co-solute i.e., both hydrocolloid and co-solute affects dissolving rate and hydrocolloid solubility by competing for available water, thereby altering the hydration

state of the polysaccharide. This transition contributes to the stabilization of intermolecular hydrogen bonding between individual hydrocolloid strands in the junction zone between the OH-groups of the co-solvent sugar and hydrocolloid, thus facilitating biomolecule-biomolecule association. Such a change in hydrocolloid cross-linking induces changes in rheological characteristics and elevation of gelation temperature (Stenner, Matubayasi, and Shimizu 2016) for example, presence of co-solutes such as sucrose increases gelling and melting temperatures of carrageenan solution (Alba and Kontogiorgos 2018). The addition of sugar in agar solutions also promotes increased gel strength and higher gelation temperatures (Vilgis 2015). The HE pectin gel network is made relevant by modifying its solvent structure, forcing the pectin chains into hydrophobic network structure (Figure 12).

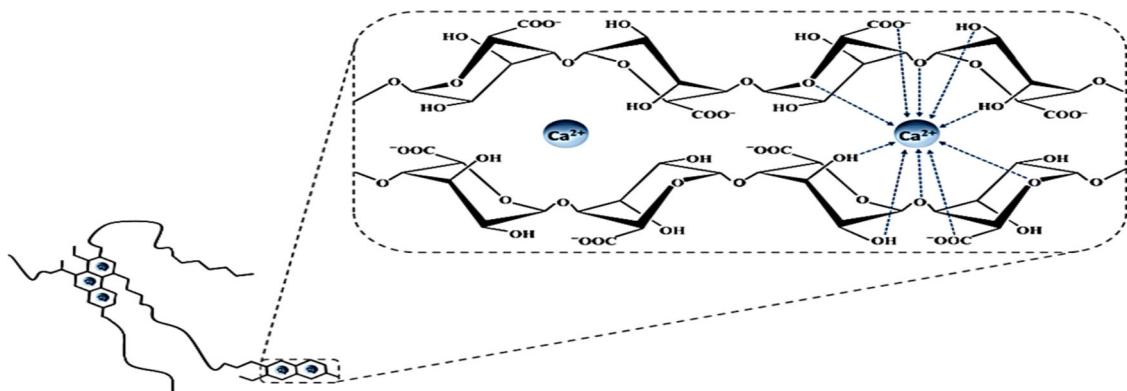
#### Temperature

The dissolution temperature depends on gelling agent concentration, ionic strength, and presence of co-solutes (Glicksman 1982). Up to  $70^\circ\text{C}$ , carrageenan dispersions are heated (Nussinovitch 1997). With the electrostatic repulsions from adjacent polymer chains and cooling at  $40$ – $60^\circ\text{C}$ , the conformational transition of carrageenan from coil-to-double helix leads to dramatic increase in viscosity. The final transition takes place in the presence of cations leading to the helix-helix aggregation of the adjacent spiral chains which contain sulfate groups to form a stable three-dimensional network (Piculell 2006). Typically, higher the concentration of cation, greater is the gelling temperature and gel strength (Alba and Kontogiorgos 2018).

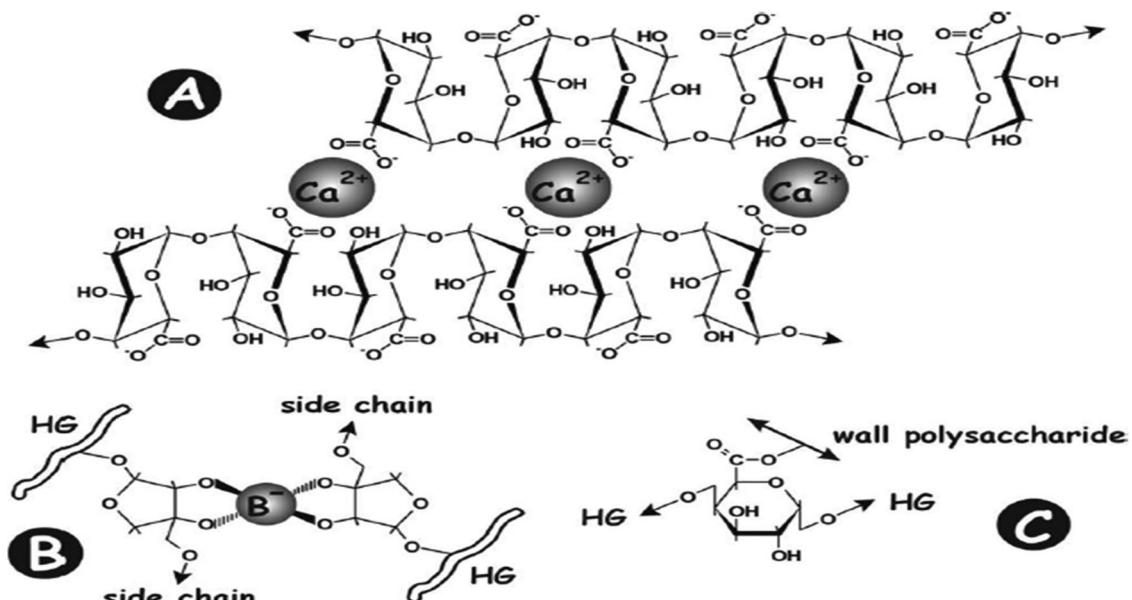
Agar dispersions requires heating above  $80^\circ\text{C}$  (Stanley 2006) to adopt random coil conformation which joins to frame a double helical association by intramolecular hydrogen bonding followed by aggregation helices by means of intermolecular hydrogen bonding into a three-dimensional network (Normand et al. 2000; Armisen and Galatas 2009). Furthermore, the presence of co-solutes, for example, sucrose likewise builds gelation and melting temperatures of hydrocolloids, resulting in increased gel strength (Vilgis 2015).

#### Interaction with other hydrocolloids

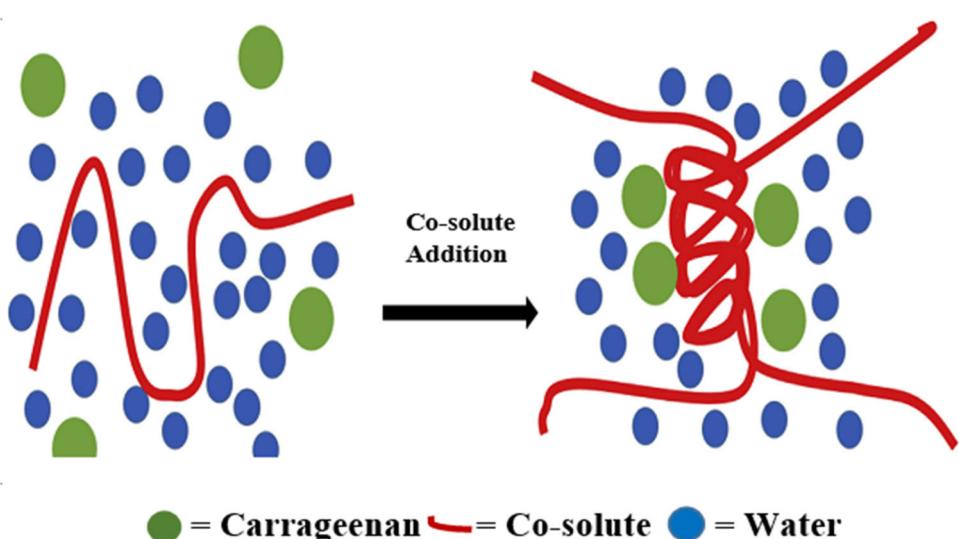
The use of a single gelling agent may create a gel that has certain drawbacks like poor structural integrity, inadequate



**Figure 10.** Cross linking of alginate molecules, Martau, Mihai, and Vodnar (2019).



**Figure 11.** Cross linking of pectin molecules, Vincken et al. (2003).



**Figure 12.** The gelation of carrageenan with co-solute adopted from Stenner, Matubayasi, and Shimizu (2016).

stability during processing and environmental conditions, unacceptable appearance, shorter shelf-life and syneresis effect. This leads to the idea of mixed gelation arises by combining multiple gelling agents with appropriate solutes

to give food products enhanced rheological features or to aid in the production of new products as shown in Figure 13 (Phillips and Williams 2009; Aguilera and Rademacher 2004).

If two hydrocolloids interact or associate, precipitation or gelation may likely to take place, for example, a protein below its isoelectric point and an anionic polysaccharide, which are opposite to loading hydrocolloids are likely to interact and precipitate according to pH, mixing ratio and ionic strength of the solution. Certain stiff polysaccharide, such as xanthan gum, carrageenan, etc. associate with galactomannans and glucomannans leading to gel formation. Hydrocolloids in this system are tightly bound by strong intermolecular interaction. The texture and nature of the gel thus differs completely from that of a single gel component. It is therefore extremely necessary for new texture and new applications (Phillips and Williams 2009).

On the other hand, if both hydrocolloids are separated or disassociate, for instance at a low hydrocolloid concentration, they tend to exist as a single homogeneous phase, whereas they will separate in time into two liquid phases at higher hydrocolloid concentrations resulting in phase

separation mechanism one phase is dispersed and other will be continuous phase. The dispersed or continuous phase relies upon the relative concentrations of hydrocolloid (Figure 14). If either or both of the hydrocolloids can form gels independently, then phase separation and gelation will occur simultaneously (Phillips and Williams 2009).

### **Synergistic mechanism of binary/two component gel system**

Two hydrocolloid components are used for the creation of gel in the binary component gel system. The portion of the hydrocolloid that forms the gel network is known as “Active” polymers whereas that portion which is contained within the network is known as “Non-active polymers.” There are two types of binary gel system namely, Type I and Type II (Banerjee and Bhattacharya 2012).

1. Type I: This type of gel system consists of a mixture of active and non-active polymers. In these gels, one hydrocolloid is capable of altering the gelling characteristics of other hydrocolloids without undergoing any direct interaction between them.
2. Type II: In this type of hydrocolloid gel system, both polymers are active and capable of forming gel networks. There are four types of network formed by the Type II binary gel system: (Oakenfull 1987).
3. In this system, one polysaccharide forming gel network and other polysaccharide network chains in random coils are enclosed/entrapped in it, example mixed gel of locust bean gum and  $\kappa$ -carrageenan.
4. Interpenetrating networks: Two polymers connect through mutual entanglements (Sikora, Kowalski, and Tomasik 2008) by creating a solitary polymer network and afterward acquainting a second polymer to gel within the preexisting network. Both polysaccharides form independent gel networks which commonly interact with one another and may form gel at a very low

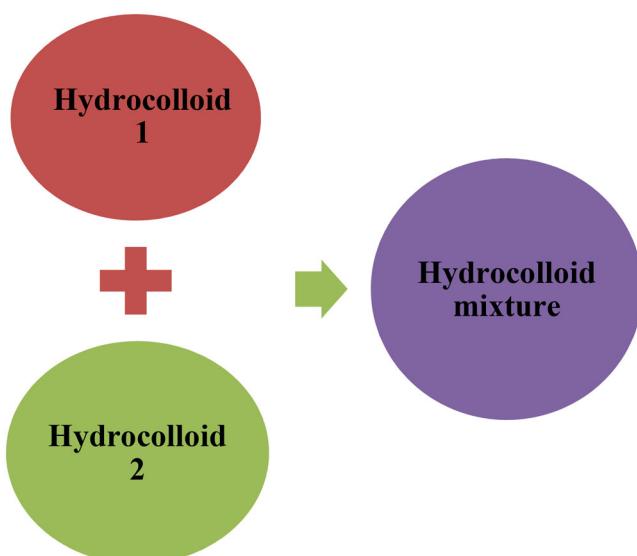


Figure 13. Hydrocolloid mixture.

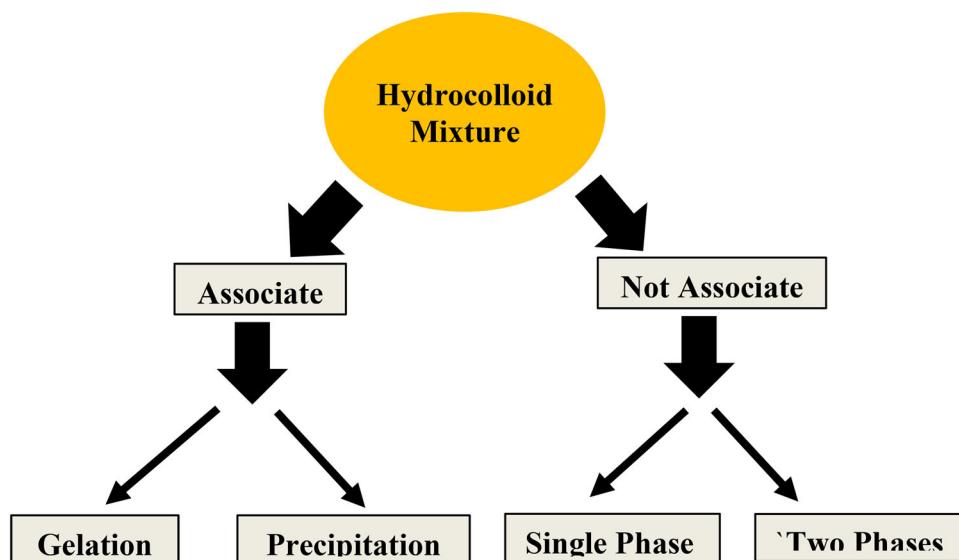


Figure 14. Interaction of hydrocolloid mixture.

- concentration for instance,  $\kappa$ -carrageenan blended with galactomannans.
5. Phase-separated network: Significant changes in the melting point and modulus of elasticity shows phase-separated network. Concentrated dispersion of mixed polymers including proteins and polysaccharides, result in phase separation and de-mixing, for instance, mixed gels of agar and gelatin (Lundin et al. 2000; Loren et al. 2001).
  6. Coupled network: Gelation can be made conceivable if the two polymer chains are consolidated by intermolecular bonding under favorable interaction. This structure originated from gel forming polymers with chemical crosslinks at least in some junction zones. This type is more common for synergistic interaction among binary polysaccharide systems (Zasyplkin, Braudo, and Tolstoguzov 1997).

### Conclusion and opportunities for future research

The principle and most significant issue that needs to be tackled for future generation is the food and plastic waste which is currently neglected by the society. The demand for inexhaustible renewable resources in the food industry contributes to increased sustainability to boost cost-effectiveness and fulfill consumer demands. Innovative research has considerable complexity that can give a wide range of novel alternatives and solutions to end products through advanced valorization strategies simultaneously. Waste valorization is a promising concept that has gained a lot of publicity over the past few years as a possible solution to the disposal of a wide variety of waste. Therefore, researchers not only develop valorization techniques but also concentrate on creating greener materials using a variety of green technologies.

The scope of natural and edible hydrocolloids in the food industry is broad and they also coincide with the current food innovation trends such as controlled delivery of functional bioactive components, production of lower calorie foods, and development of edible tablewares. Such drivers mean that more research on these edible hydrocolloids, which could support the food sector and contribute to sustainable development will be anticipated with substantial improvement. This review has focused to provide a comprehensive introduction to natural edible hydrocolloids by providing descriptions in terms of their origin, properties, and potential uses, merits, demerits and applications. Owing to the advantages in terms of the use of natural edible hydrocolloids over synthetically derived hydrocolloids, edible hydrocolloids have achieved significant consideration in modern times, which can practically diminish the complexity and thus increase material recyclability compared to the conventional non-environmental friendly materials.

Although edible polymers have some issues including low mechanical strength, flexibility problems, and polymer diffusion, mixed composition can overcome such problems and change them as required. Most of the studies on edible hydrocolloids and bio-waste have been conducted at a laboratory scale. However for a commercial breakthrough, a continued development of functionality and processing is needed. Henceforth, in order to provide more reliable

details, more studies should be focused on a commercial scale. In a current scenario where natural edible hydrocolloids are replacing petroleum-based products. However, due to their hydrophilic nature, the low water vapor barrier property is one of the key disadvantages of the natural edible hydrocolloids. Blending of natural hydrocolloids with different properties has been regarded as new alternative to change the properties of natural hydrocolloids and create novel composite materials with desirable properties compared to the individual component, for instance, the blending of various natural hydrocolloids such as agar, carrageenan, pectin, alginate etc for the development of packaging films has been investigated to exploit the improvement of packaging properties due to their variation in physical properties and/or their interaction. Therefore, the selection of the high compatibility blending components is one of the most critical factors to completely exploit the beneficial impact of blended materials.

Thus, on the basis of current review, out of all the natural edible hydrocolloids, agar which is a gelatinous food hydrocolloid additive extracted from red seaweeds and is generally recognized as safe by FDA is considered as the best due to its explicit number of properties such as high mechanical strength, high temperature tolerance, moderate water resistant, high gelling strength, stability under acidic conditions and most importantly limited reacted with the other food components. Nowadays, it has been widely used for preparation of packaging films, bio-waste based bioplastic etc. It also has extensively been used in blends with other hydrocolloids to improve physical and mechanical properties of other hydrocolloids such as carrageenan, starch, protein, gelatin.

In many areas, there are a number of significant features of natural edible hydrocolloids which display exceptional characteristics. In order to achieve circular economy, sustainable efforts are therefore required to create an innovative and integrated strategy to combat bio-waste as well as plastic waste using these natural edible hydrocolloids to overcome several issues such as improving processing efficiency, increasing profitability, and exploration of the “Taste over Waste” approach which contributes to overall sustainability.

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