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Hydrocolloids as multifunctional biopolymers: From food texture to therapeutic potential

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Abstract

Hydrocolloids are a group of water-soluble proteins and polysaccharides valued for their unique texture and structure. They are used to design sensory and physical resemblances associated with freshness, creaminess, and desired quality. Their high molecular weight and hydrophilic nature allow them to dissolve or disperse in water, forming stable colloidal systems. It binds and immobilizes water, helping in texture development, moisture retention, and enhancing shelf-life. It acts as a thickener by increasing the viscosity of liquid foods, enhancing mouthfeel and stability. Hydrocolloids create three-dimensional networks via gelation, producing viscous fluids to rigid gels, extending from soft gels in jams to firm structures in bakery products. Hydrocolloids ensure uniformity and consistency in processed foods, preventing issues such as phase separation, crystallization, and rapid staling. Moreover, hydrocolloids serve as dietary fibers, contributing to improved digestive health, glycemic regulation, and satiety. Their inclusion in foods can modulate the release of nutrients and flavors, enhance the perception of saltiness, and promote the growth of beneficial gut microbiota. The role of hydrocolloids as silent architects of food structure will become more pronounced, shaping the future of food design and technology. This review explores the diverse sources and classifications of hydrocolloids, their molecular interactions in food systems, and functional applications ranging from texture modulation to health enhancement. Special attention is given to their nutritional benefits, emerging trends, future market potential, research gaps, and regulatory challenges.

1. Introduction

Hydrocolloids are a diverse and indispensable class of high-molecular-weight, hydrophilic polymers that have revolutionized multiple industrial sectors, most notably food, pharma, and cosmetics. Defined by their remarkable ability to disperse or dissolve in water, hydrocolloids form viscous solutions or gels even at low concentrations. They impart distinct physicochemical properties such as gelling, thickening, stabilizing, and emulsifying (Williams and Phillips, 2003). The term “hydrocolloid” refers to materials that create colloidal systems when combined with water, although not every hydrocolloid solution is a colloid in the strict physical chemistry sense (Goff and Guo, 2019). Hydrocolloids are primarily polysaccharides and proteins sourced from plants, animals, microbes, seaweeds, or via chemical modification, whose molecular structures enable strong interactions with water molecules. Hydrocolloids are typically classified based on their chemical structure, origin, and ionic properties. They can be categorized into four main groups based on their source: plant-derived, animal-derived, microbial-derived, and

chemically modified hydrocolloids, represented in Figure 1 (Yemeniciođlu *et al.*, 2020). Structurally, hydrocolloids can be linear, such as cellulose and pectin, or branched, like dextrans and certain gums, influencing their gelation and thickening properties. They may also be classified as non-ionic, anionic, or cationic based on their ionic charge, affecting their behavior in different pH and ionic environments (Nepovinnykh and Petrova, 2025).

In aqueous environments, hydrocolloids swell on absorbing water and increase their volume, which in turn raises the viscosity of the matrix. At higher concentrations or under modified conditions (such as changes in pH or ionic strength), hydrocolloids entrap sufficient water molecules, allowing their polymeric chains to interact and form an interlinked network that results in a gel-like structure or matrix. As a result, a very low concentration of hydrocolloid is sufficient to influence the food structure (O’Sullivan and O’Mahony, 2016). This versatile nature of application ensures that hydrocolloids will continue to lead innovations across multiple sectors as research and technology continue to advance.

In the food industry, hydrocolloids are vital for their multi-functional behavior. They act as thickeners and gelling agents, such as agar, carrageenan, and gelatin, creating a spectrum of textures, while others, like xanthan gum and guar gum, enhance viscosity and mouthfeel. The water-binding capacity underpins their core functionalities such as modifying texture, viscosity, and stability in various food and non-food products (Yang *et al.*, 2009). For example: Gum Arabic/

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acacia, commonly used in bakery, pharmaceuticals and cosmetics, is a gum is a mixture of polysaccharides and glycoproteins (Sharma *et al.*, 2023). Hydrocolloids also stabilize emulsions and foams by enhancing the viscosity of the continuous phase, also prevent phase separation at the same time in products like salad dressings and whipped toppings. Their ability to modify and control texture is crucial for consumer acceptability and product differentiation in dairy desserts, bakery items, and confectionery. Furthermore, hydrocolloids extend shelf-life by retarding staling in baked goods and inhibiting ice crystal growth in frozen foods (Edmund, 2023; Williams and Phillips, 2003; Yang *et al.*, 2009). Beyond their technological roles, many hydrocolloids serve as dietary fibers, contributing to digestive health, glycemic control, and satiety. Hydrocolloids are also used as fat replacers or sugar substitutes in the development of reduced-calorie and functional foods (Rasul *et al.*, 2025; Zhao *et al.*, 2023).

The significance of hydrocolloids extends far beyond food. In pharmaceuticals, they are used as excipients in drug delivery systems, wound dressings, and controlled-release formulations, capitalizing on their biocompatibility and viscosity-modulating properties. In cosmetics, hydrocolloids enhance the stability and texture of creams, lotions, and gels, while in industrial applications, their rheological properties are exploited in adhesives, coatings, paints, and drilling fluids (Edmund, 2023). Increasing demand for clean-label, plant-based, and functional products, brought hydrocolloids to become a focal point of modern product development and food science (Gao *et al.*, 2024).

Novel studies are focusing on the development of smart and responsive biopolymer hydrogels for targeted drug delivery, cancer treatment, tissue engineering, and wound healing. These next-

generation biopolymer gels can respond to environmental stimuli like temperature and pH to control drug release, enhance therapeutic effects, and support tissue regeneration (Shergujri *et al.*, 2025). These advancements in hydrocolloid-based coatings are creating sustainable bio-based packaging solutions that improve food preservation and reduce environmental impact (Debeaufort *et al.*, 2025). This review summarizes the various aspects of hydrocolloids as multifunctional biopolymer molecules. The cutting-edge applications of hydrocolloids fulfill critical structural and functional roles in many industries.

2. Classification and sources of hydrocolloids

Hydrocolloids are grouped reflecting diverse sources and applications in food and industrial systems (Figure 1). Plant-derived hydrocolloids, such as pectin (extracted from fruit rinds), locust bean gum and guar gum (from seeds), and cellulose derivatives (like methylcellulose from plant cell walls), are gaining prominence due to consumer demand for natural, vegan-friendly ingredients. Seaweed-derived hydrocolloids, including agar, carrageenan, and alginate, are extracted from marine algae and prized for their gelling and water-binding properties, particularly in dairy alternatives and processed meats. Microbial hydrocolloids, such as xanthan gum produced via *Xanthomonas campestris* fermentation, offer consistent functionality under varying pH and temperature, making them ideal for sauces and gluten-free baked goods. Animal-derived hydrocolloids, notably gelatin (sourced from collagen), remain irreplaceable in confectionery and pharmaceutical capsules due to their thermo-reversible gelling. Further, synthetic and semi-synthetic hydrocolloids (CMC, HPMC, *etc.*) are engineered for specialized industrial applications, providing improved viscosity and stability in products ranging from paints to processed foods (Gautam *et al.*, 2024; Saha and Bhattacharya, 2010; Yang *et al.*, 2020).

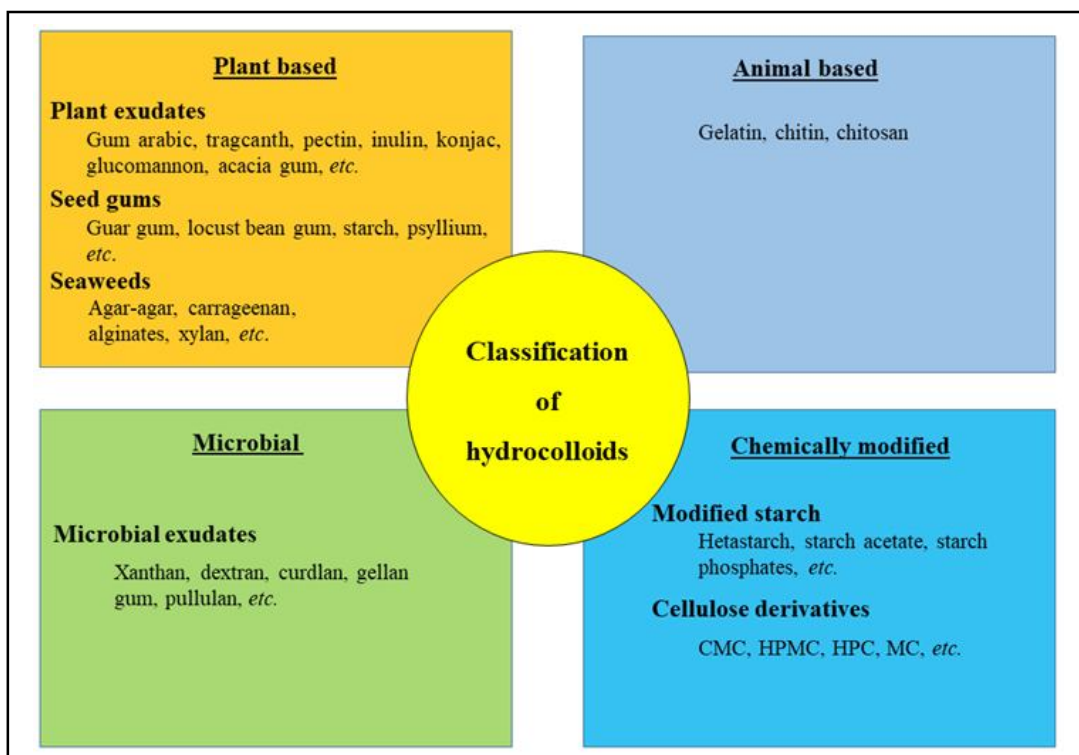


Figure 1: Classification of hydrocolloids.

3. Molecular behavior of hydrocolloids

The molecular behavior of hydrocolloids depends on their polysaccharide or protein structures, which enable them to bind water, swell, and form gels. Structurally, hydrocolloids are composed of long-chain molecules that can be linear or branched, often featuring repeating sugar units (in polysaccharides) or amino acids (in proteins like gelatin). The presence of various side groups (such as carboxyl, sulfate, or methyl ether groups) on these chains greatly influences their solubility, gelling, and thickening abilities (Lu *et al.*, 2021).

When dissolved or dispersed in water, hydrocolloid molecules interact extensively with water molecules through hydrogen bonding and other polar interactions. This leads to the formation of highly viscous solutions or gels, even at low concentrations. The viscosity and gel strength are largely determined by the length of the molecular chain, *i.e.*, longer chains increase the frequency of intermolecular collisions and friction, resulting in higher viscosity (Gao *et al.*, 2024). Additionally, the ability of hydrocolloids to form network structures

in solution is crucial for their thickening and gelling functions. Further junction zones are formed at specific regions where multiple polymer chains associate through hydrogen bonding, ionic interactions, or calcium bridging (Li *et al.*, 2023). The number and strength of these junction zones dictate the rigidity, flexibility, and thermal stability of the resulting gel. For example, λ -carrageenan forms multi-molecule junction zones, creating rigid gels, while gelatin forms triple helix junctions *via* hydrogen bonds, resulting in more flexible gels that melt at lower temperatures. Alginate gels, stabilized by calcium bridges, can withstand high temperatures due to the strength and cooperativity of these ionic junctions (Saha and Bhattacharya, 2010).

The molecular behavior of hydrocolloids is greatly influenced by environmental factors such as pH, ionic strength, temperature, and the presence of co-solutes, affecting their solubility, gelation, and viscosity (Table 1). Overall, the molecular structure, chain length, branching, side groups, and ability to form junction zones directly govern the rheological and functional properties of hydrocolloids in food and industrial applications.

Table 1: Physicochemical properties of common hydrocolloids (Williams and Phillips, 2003)

Hydrocolloids	Solubility	pH Stability	Gelation temperature	Sensitivity	Functional properties
Agar	Hot water (>80°C)	5-9	30-40°C (gels)	Acidic hydrolysis	Thermo-reversible gels, high gel strength
Sodium alginate	Cold water	5-9	Room temp (Ca ²⁺ -induced)	Calcium-dependent	Heat-stable, ionotropic gelation
Carrageenan	Hot water	6-9	30-70°C (type-dependent)	Ionic strength	Thickening, gelation with K ⁺ /Ca ²⁺
Gelatin	Hot water	3-10	<35°C (cools)	Heat, proteases	Thermo-reversible gels, elasticity
Pectin	Hot water (acidic)	2.5-3.5	60-90°C (with sugar)	pH, divalent cations	Gelation in high-sugar/acid systems
Xanthan gum	Cold/hot water	2-12	Non-gelling	High temp (>88°C)	Shear-thinning, stable viscosity
Guar gum	Cold water	4-10.5	Non-gelling	Heat-stable	High viscosity, synergizes with LBG
Locust bean gum	Hot water	5-11	Non-gelling	Requires heat for hydration	Synergistic gelation with λ -carrageenan
CMC	Cold/hot water	4-10	Non-gelling	Ionic strength	Thickening, pseudoplastic flow
Methyl cellulose	Cold water	3-11	Gels at >50°C	Thermo-reversible	Heat-induced gelation
Gum Arabic	Cold water	2-10	Non-gelling	High salt concentrations	Emulsification, low viscosity

3.1 Hydration and swelling

The hydrocolloid's functional properties are significantly influenced by its ability to hydrate and swell. Hydration begins when a water molecule penetrates into the hydrocolloid molecule. This involves solvent diffusion into the polymer network, driven by differences in chemical potential between the hydrocolloid and its surroundings (Morreale *et al.*, 2018; Williams and Phillips, 2003). Hydrocolloids with hydrophilic groups (*e.g.*, hydroxyl, carboxyl) attract water through hydrogen bonding and dipole interactions. High molecular weight hydrocolloids (*e.g.*, guar gum) hydrate more slowly due to larger chain sizes but form more viscous solutions once dissolved.

High temperature accelerates the hydration in some hydrocolloids such as starches, whereas modified cellulose is soluble at a lower temperature. Charged hydrocolloids (*e.g.*, alginate, pectin) exhibit pH-dependent solubility. At low pH, carboxyl groups protonate, reducing electrostatic repulsion and hydration (Rather *et al.*, 2025; Saha and Bhattacharya, 2010).

Swelling occurs as absorbed water disrupts intermolecular bonds, causing polymer chains to expand. Swelling is influenced by osmotic pressure as water influx creates a balance between osmotic forces (driving swelling) and elastic retraction of the polymer network (Jia *et al.*, 2023). Cross-linked hydrocolloids (*e.g.*, hydrogels) swell until

elastic forces counteract osmotic pressure, limiting expansion. Linear polymers (e.g., sodium alginate) swell more freely than branched ones (e.g., amylopectin). Divalent ions (e.g., Ca^{2+}) cross-link anionic hydrocolloids like alginate, reducing swelling. Monovalent ions (e.g., Na^+) screen charges, moderately lowering hydration (Kowalski *et al.*, 2024).

3.2 Solubility

The solubility of hydrocolloids is essential for their functional performance, as it enables effective dispersion within food systems. The dissolution of hydrocolloids depends upon a continuous hydration process, which converts intermolecular bonds to molecule-water binding (Williams and Phillips, 2003). Factors such as particle size, temperature and ionic charges significantly affect the dissolution of hydrocolloids. For example, coarse powder dissolves more slowly than fine powder due to more penetration time. Finer hydrocolloid particles rapidly hydrate on their surface, forming a gel layer that traps dry powder inside, commonly referred to as “fish eyes”. This leads to lump formation and uneven dispersion. Proper agitation, such as high-shear mixing, ensures uniform dispersion and prevents these agglomerates (Godoi *et al.*, 2021). High temperature ($<80^\circ\text{C}$) also facilitates the solubility of hydrocolloids. In some cases, calcium ions cause gelation before proper dispersion of hydrocolloid (alginate and pectin) in water. Hydrocolloids usually less than 1% is sufficient to bring a functional effect in the food matrix (Gawai *et al.*, 2017). Hydrocolloids demonstrate different solubility conditions due to their structural and conformational difference. For example, gum arabic and pullulan are easily soluble in cold water. Whereas starch solubilizes in hot water (Gao *et al.*, 2024; Goff and Guo, 2019).

3.3 Gelation

Gelation occurs in hydrocolloids when polymer chains form a three-dimensional network that traps water, transforming a liquid into a semi-solid gel. The gelation in hydrocolloid are induced by multiple factors: Thermally induced gels such as gelatin (require heat to dissolve, then cooled to form helical junctions *via* hydrogen bonds), agar (forms rigid gels on cooling as double helices aggregates), methylcellulose (shows reverse thermal gelation due to hydrophobic interactions) (Liu *et al.*, 2016), ionotropic gels such as alginates (cross-linked by Ca^{2+} ions, forming an “egg-box” structure between guluronate chains), pectin (requires Ca^{2+} for gelation, similar to alginate), carrageenan (gels with K^+ ions, forming helical bundles) (Gadziński *et al.*, 2022); Acid induced gels such as high-methoxyl pectin (forms gels at low pH (<3.5) and high sugar content (55%), as reduced electrostatic repulsion allows hydrophobic interactions) (Xia *et al.*, 2022), and synergistic gels such as xanthan with locust bean gum (helical xanthan binds to LBG’s galactose-free regions, forming strong gels), *etc.* (Li *et al.*, 2024).

The mechanism explains gelation of hydrocolloids when heating of aqueous solution is done, the double helical structure disintegrates and forms a single chain conformation (*i.e.*, a disordered coil structure). Which again on cooling, the molecules start binding each other in order to form a double helical structure by hydrogen bonding and van der Waals forces. This mechanism leads to the formation of thermo-reversible gels. Further, the available cations promote gelation by reducing electrostatic repulsion and forming more hydrogen bonds

to strengthen the inter-helical association of polysaccharide molecules. This increases thermal stability and produces an enlarged thermal hysteresis curve during sol-gel transformations (Burey *et al.*, 2008; Funami *et al.*, 2025).

For hydrocolloids to gel, polymer molecules or bundles of polymer molecules must adhere through hydrogen bonds or cross-linking of negatively charged molecules by multivalent cations, typically calcium ions or protein molecules along segments of their lengths, resulting in the formation of junction zones. This creates a 3-D network that traps water, like a sponge (Goff and Guo, 2019). Most polysaccharide gels are thermos-reversible in nature, and inadequately maintain the network in a heated dough, resulting in insufficient retention of gas bubbles and the formation of an appropriate open cellular structure. Most junction zones (gels) fail to reform following disruption by shear forces. The molecules must be dissolved again, typically through heating, and subsequently allowed to partially precipitate from the solution, usually by cooling (BeMiller, 2008).

4. Interaction with other food constituents

Hydrocolloids significantly affect the food matrix, as they consist of various chemically reactive groups. Proteins have S-H, S-S, N-H whereas carbohydrates have O-H, C-H-O, C=O. These functional groups helps to interact with each other in a food matrix (Yemeniciođlu *et al.*, 2020). The interaction of hydrocolloids with other food constituents significantly affects functional properties and other quality attributes (color, texture and flavor). Protein-based hydrocolloids interact with polyphenols via hydrogen bonding, which occurs between the hydroxyl groups of polyphenols and the carbonyl groups of proteins, as well as through hydrophobic interactions (Bandyopadhyay *et al.*, 2012). Polysaccharide-based hydrocolloids contain polar groups, such as acetal, hydroxyl, or carboxyl, which interact with and bind to phenolic-OH groups through hydrogen bonds and van der Waals forces (Palafox Carlos *et al.*, 2011; Wu *et al.*, 2009). Also, Ionic connections with polyphenols may also be established. The interaction between hydrocolloids and polyphenols affects the functional properties and leads to significant changes in the stability, bioavailability, and bioactivity of polyphenols (Jakobek and Matie, 2019; Palafox Carlos *et al.*, 2011; Yemeniciođlu *et al.*, 2020).

5. Functional applications of hydrocolloids

A wide variety of hydrocolloids have been receiving more attention from researchers in recent years. Various food products consist of hydrocolloids in multiple ways, including thickeners, gelling agents, emulsifiers, and fat replacers (Pirsa and Hafezi, 2022). They have physicochemical properties that improve sensory properties, shelf-life, and encapsulation systems. Thickening properties enhance sensory properties in soups, sauces, salad dressings, and condiments. Gelling and emulsifying properties improve puddings, jellies, and ice cream. Film-forming properties enhance the shelf-life of new food products and protect bioactive compounds during digestion (Pirsa and Hafezi, 2022). Hydrocolloids are used for functionality and nutritional benefits, such as adding viscosity or gelation to food systems. These properties are a manifestation of the polymer’s chemical structure and conformation, and are often referred to as stabilizers (Goff and Guo, 2019).

Table 2: Functional application of hydrocolloids in food products

Food products	Hydrocolloids	Key applications	Functional application	References
Dairy products	Carrageenan, guar gum, alginate	Chocolate milk, yogurt, cheese, ice cream	Stabilizes proteins, prevents water separation, improves creaminess, prevents ice crystal growth	Xu <i>et al.</i> , 2023
Bakery	Xanthan gum, guar gum, pectin	Bread, gluten-free products, cakes	Enhances dough elasticity, improves texture, increases moisture retention, adds dietary fiber	Barman <i>et al.</i> , 2021
Beverages	Xanthan gum, guar gum, pectin	Juice drinks, bottled beverages, smoothies	Stabilizes suspensions, prevents sedimentation, improves mouthfeel	Pegg, 2012
Confectionery	Agar, gelatin, carrageenan, pectin	Gummies, jellies, marshmallows, fruit chews	Provides gelling, controls texture, enables clear and stable gels	Bagal kestwal <i>et al.</i> , 2019
Sauces and dressings	Xanthan gum, guar gum, cmc	Salad dressings, mayonnaise, sauces	Thickens, stabilizes emulsions, prevents phase separation, ensures pourable consistency	Tahmouzi <i>et al.</i> , 2023
Meat and processed foods	Alginate, carrageenan, cmc	Sausages, restructured meats, deli products	Improves water retention, enhances texture, reduces fat, binds ingredients	Bao <i>et al.</i> , 2025
Frozen desserts	Guar gum, locust bean gum, carrageenan	Ice cream, sorbet, frozen yogurt	Prevents ice crystal formation, improves smoothness, stabilizes air incorporation	Gajo <i>et al.</i> , 2017
Functional and health foods	Inulin, pectin, beta-glucan	Fiber-enriched foods, low-gi foods, probiotic products	Adds soluble fiber, supports prebiotic activity, enables delivery of bioactives	Li and nie, 2016
Edible films and packaging	Alginate, pectin, chitosan	Edible coatings for fruits, vegetables, meats	Forms protective barrier, extends shelf-life, can carry antimicrobials or antioxidants	Jiménez <i>et al.</i> , 2018; Rai <i>et al.</i> , 2020

Hydrocolloids have broad application in various food and non-food industries due to their functionality (Tables 2 and 3). In the dairy industry, guar gum, carboxymethyl cellulose, and xanthan gum serve as thickening agents in products like flavored milk, milkshakes, and ice cream (Hansen, 1994). Gelling agents like carrageenan, agar, and cellulose contribute to achieving the desired texture in yogurts and cottage cheese. They inhibit sedimentation in chocolate milk and minimize whey separation in yogurts. Hydrocolloids serve to stabilize emulsions and suspensions, thereby maintaining product consistency over its shelf life. Hydrocolloids such as guar gum serve as fat replacers in low-fat dairy products, enhancing mouthfeel and sensory acceptability while decreasing hardness in cheese. Hydrocolloids inhibit syneresis, thereby preserving product quality and extending shelf-life (Yemeniciođlu *et al.*, 2020; Yousefi and Jafari, 2019).

In the meat industry, hydrocolloids enhance the texture and water retention of meat products (Dinani *et al.*, 2023). They mitigate the adverse effects associated with the reduction of fat and salt, in addition to addressing freeze-thaw cycles. In poultry nuggets, the incorporation of hydrocolloids in batter coatings minimizes oil absorption during frying and enhances moisture retention. Hydrocolloids improve gel strength and water retention in processed meats, resulting in a firmer and juicier product (Gao *et al.*, 2024; Sarteshnizi and Khaneghah, 2015). In the bakery and confectionery industry, hydrocolloids improve the texture, volume, and structure of bread crumb, very useful in gluten-free products. Hydrocolloids help keep bread and cakes fresh by binding water and also slow down the ageing process (Sundharaiya *et al.*, 2025). Resistant starches and other hydrocolloids add fiber and health benefits to baked goods.

Hydrocolloids, like pectin and gelatin, are needed for things like sweets, marshmallows, and jellies to gel and foam. They give different kinds of candy with the chewiness, elasticity, or hardness that people want. Hydrocolloids prevent sugar from crystallizing, which keeps sweets and fillings smooth (Ishaq *et al.*, 2024; Yemeniciođlu *et al.*, 2020).

Hydrocolloids preserve desired sensory qualities by improving the texture and stability of fruit purees, juices, fillings, and leathers, therefore preventing phase separation. Moreover, helps to preserve nutrients and increase the thermal stability of fruit-based goods throughout storage and processing. In fruit preparations, hydrocolloids help to minimize water separation, therefore guaranteeing a consistent product quality (Alam *et al.*, 2025). The non-food application includes its usage in medicines, wound dressings, hydrogels, face masks, beauty products, shampoos, tooth pastes, wall paints, coatings and films (Rai *et al.*, 2020) (Table 3).

6. Health and nutritional aspects

Hydrocolloids are widely recognized not only for their functional roles in food systems but also for their significant health and nutritional benefits (Table 4). As modern consumers increasingly seek foods that support wellness, hydrocolloids have gained attention for their contributions to digestive health, weight management, glycemic control, cardiovascular health, and more (Li and Nie, 2016). Many hydrocolloids, such as pectin, guar gum, psyllium, and beta-glucans, are rich sources of soluble dietary fiber, are utilized in the preparation of functional foods (Ullagaddi and Murkhand, 2024). When consumed, these substances absorb water and form viscous

gels in the digestive tract, which slows gastric emptying and promotes regular bowel movements. This gel-forming ability not only alleviates constipation but also helps maintain stool consistency and ease of passage, supporting overall digestive health. Furthermore, hydrocolloids can create a protective barrier on the intestinal lining, potentially reducing the risk of harmful bacteria adhering to the gut walls and thus lowering the risk of infection (Pirsa and Hafezi, 2022). Hydrocolloids function as a prebiotic, which stimulates the growth

of probiotic bacteria such as *Lactobacillus* and *Bifidobacterium* in the gut (Davani-Davari *et al.*, 2019). The fermentation of these soluble dietary fibers in the colon produces short-chain fatty acids (SCFAs), crucial in maintaining colon health, modulating immune responses, and reducing inflammation (Devi *et al.*, 2021). Regular intake of hydrocolloid-rich foods has been linked to improved gut microbiota composition and increased fermentative activity, further supporting gastrointestinal well-being (Sharma and Sarwat, 2022).

Table 3: Non-food application of hydrocolloids

Non-food sectors	Hydrocolloids	Key applications	Features of use	References
Pharmaceuticals	Alginate, pectin, guar gum, carrageenan, xanthan gum	Drug delivery systems, controlled-release tablets, gummies	Biocompatibility, controlled drug release, encapsulation, moisture retention, gel formation	Lomartire and Gonçalves, 2023; Rawat <i>et al.</i> , 2024
Wound care	Gelatin, sodium CMC, alginate, pectin	Hydrocolloid dressings, moist wound healing	Forms protective gel barrier, absorbs exudate, promotes autolytic debridement, reduces infection risk	Pirsa and Hafezi, 2022
Cosmetics and personal care	Xanthan gum, carrageenan, alginate, gum Arabic	Creams, lotions, shampoos, toothpaste	Thickening, stabilizing, moisturizing, forming protective film, improving texture	Kanlayavattanakul and Lourith, 2015
Tissue engineering	Alginate, gelatin, chitosan	Scaffolds for cell growth, regenerative medicine	Biodegradability, cell compatibility, structural support	Pele <i>et al.</i> , 2023
Industrial/manufacturing	Guar gum, xanthan gum, CMC, agar	Adhesives, coatings, paints, drilling fluids	Rheology modification, thickening, stabilization, water retention	Razavi, 2019
Biotechnology	Agar, carrageenan, alginate	Microbial culture media, enzyme immobilization	Gelling, stabilizing, supporting cell growth and enzyme activity	Kurbanova <i>et al.</i> , 2023
Packaging/biodegradable materials	CMC, alginate, pectin, chitosan	Biodegradable films and coatings	Edible, environmentally friendly, barrier properties, can carry antimicrobials	Jiménez <i>et al.</i> , 2018; Rai <i>et al.</i> , 2020

One of the most notable health benefits of hydrocolloids is their impact on satiety and weight management (Tárrega *et al.*, 2014). By absorbing water and expanding in the stomach, hydrocolloids trigger receptors that signal fullness to the brain, reducing hunger and the likelihood of overeating. This effect can persist for several hours, aiding portion control and decreasing the tendency to snack between meals (Paeschke and Aimutis, 2008). Clinical studies have shown that hydrocolloids like guar gum and konjac gum, when incorporated into a balanced diet, can reduce body weight, body mass index (BMI), and waist circumference (Pittler and Ernst, 2001). Additionally, hydrocolloids help moderate energy intake and support weight loss efforts by slowing the digestion and absorption of nutrients.

Hydrocolloids play a vital role in controlling postprandial blood glucose levels. Their viscous nature slows the absorption of carbohydrates in the small intestine, resulting in a more gradual rise in blood sugar after meals. This is beneficial for diabetic patients (Giuntini *et al.*, 2022). Foods formulated with hydrocolloids can thus contribute to a lower glycemic index, supporting better glycemic management and reducing the risk of insulin resistance (Karim *et al.*, 2024). Certain hydrocolloids, notably beta-glucans and psyllium, have been clinically proven to lower serum LDL cholesterol levels. These dietary fibers use cholesterol to produce more bile acids and

bind to bile acids in the gut and promoting their excretion, thereby reducing cholesterol levels (Goff *et al.*, 2018). The U.S. Food and Drug Administration (FDA) recognizes the cholesterol-lowering effects of these hydrocolloids and their role in reducing cardiovascular disease risk. Regular consumption of hydrocolloid-rich foods can thus be an effective dietary strategy for heart health (Viebke *et al.*, 2014).

Hydrocolloids are essential in gluten-free baking, where they provide structure, elasticity, and moisture retention in the absence of gluten (Anton and Artfield, 2008; Cappelli *et al.*, 2020). This makes them invaluable for people with celiac disease or gluten sensitivity. Hydrocolloids made the preparation of high-quality gluten-free breads, cakes, and other baked goods easier that closely mimic the texture and mouthfeel of traditional products (Arif *et al.*, 2025). Hydrocolloids are widely utilized in the formulation of low-calorie and reduced-fat foods due to their ability to enhance viscosity and texture without significantly increasing caloric content. By replacing fats and sugars in recipes, hydrocolloids help create healthier options that retain desirable sensory properties such as mouthfeel in various food products, such as dairy items, baked goods, and sauces (Azmoon *et al.*, 2021). They also facilitate the delivery of bioactive compounds, vitamins, and minerals, enhancing the nutritional profile of functional foods and supporting overall wellness (Pirsa and Hafezi, 2022).

Table 4: Nutritional and health benefits of hydrocolloids (Li and Nie, 2016; Pirsá and Hafezi, 2022; Williams and Phillips, 2003)

Health/nutritional benefits	Hydrocolloids	Food application	Functional role
Digestive health	Psyllium, guar gum, pectin, inulin	Breakfast cereals, supplements, bakery	Promote regularity, relieve constipation, improve stool consistency
Dietary fiber source	Pectin, beta-glucan, inulin, psyllium	Fruit jams, cereals, bakery	Provide soluble fiber, increase stool bulk, support bowel health
Gut microbiome/prebiotic effect	Inulin, guar gum, beta-glucan	Yogurt, beverages, snacks	Stimulate growth of beneficial bacteria, increase SCFA production
Weight management/satiety	Guar gum, konjac, chia seeds	Meal replacements, beverages	Form gels in stomach, increase fullness, reduce calorie intake
Blood sugar regulation	Guar gum, pectin, konjac, xanthan gum	Bakery, dairy, beverages	Slow carbohydrate absorption, lower postprandial blood glucose
Cholesterol reduction/heart health	Beta-glucan, psyllium, pectin	Oatmeal, cereal bars, supplements	Lower LDL cholesterol by binding bile acids, support cardiovascular health
Calorie reduction	Agar, xanthan gum, carrageenan, konjac	Low-fat dairy, desserts, sauces	Replace fats/sugars, allow low-calorie and reduced-fat foods
Texture/sensory improvement	Xanthan gum, pectin, carrageenan, agar, gelatin	Dairy, sauces, bakery	Enhance mouthfeel, viscosity, and stability of foods
Gluten-free/allergen replacement	Xanthan gum, guar gum, locust bean gum	Gluten-free bakery, pasta	Provide structure and moisture retention in gluten-free/allergen-free foods
Bioactive delivery	Alginate, carrageenan, pectin	Functional foods, supplements	Encapsulate and release nutrients, vitamins, probiotics, and bioactives
Immune modulation	Beta-glucan, inulin	Supplements, cereals	Modulate immune response, support gut barrier function
Suitability for special diets	All (depending on type)	Low-salt, low-fat, vegan, plant-based foods	Used in low-salt, low-fat, low-sugar, vegan, and plant-based products

7. Emerging trends and future market

The hydrocolloids market is undergoing notable transition phase, propelled by changing consumer preferences, technological advancements, and expanding industrial applications. Globally, the hydrocolloids market was valued at approximately USD 11.23 billion in 2022 and is projected to reach between USD 17.8-20.8 billion by 2030, growing at a compound annual growth rate (CAGR) of 5-6% (GVR, 2024). This robust growth is driven by the diverse increasing demand for hydrocolloids as thickeners, stabilizers, and gelling agents in food and beverages, cosmetics, pharmaceuticals, and personal care.

One of the most prominent trends is the surge in demand for natural, clean-label, and plant-based ingredients. Increasing health consciousness among consumers has made them attentive toward product labels; there is a marked preference for food products formulated with natural hydrocolloids such as pectin, agar, and guar gum (Research and Markets, 2025). This trend is closely linked to the rising popularity of vegan and plant-based diets, where hydrocolloids replicate the texture and mouthfeel of animal-derived products. Additionally, the food and beverage industry continues to be the largest consumer of hydrocolloids, utilizing them for their aforementioned multi-functional properties, which enhance product quality and shelf life. Further expansion of hydrocolloid applications beyond the food industry. There is growing utilization in pharmaceuticals, where hydrocolloids are valued for their controlled-release and encapsulation capabilities (Dash *et al.*, 2022), as well as

in cosmetics and personal care for their texturizing and moisture-retention properties. Industrial uses are also on the rise, with hydrocolloids being incorporated into building materials, paints, coatings, and latex products due to their ability to modify flow behavior and improve product performance (IMARC, 2024).

Regionally, the Asia-Pacific regional market is expected to grow rapidly. Rapid urbanization, rising disposable incomes, and expanding food, pharmaceutical, and cosmetic industries, particularly in countries like China and India, may be seen as potential factors responsible. North America and Europe remain mature markets but continue to see growth through innovation and the introduction of specialty hydrocolloids for functional foods and health-oriented products (Research and Markets, 2025). Regulatory trends are also shaping the future market. There is increasing scrutiny regarding food safety, allergen labeling, and the sustainability of raw material sourcing. This is pushing manufacturers to adopt more sustainable practices and to develop hydrocolloids that meet both regulatory standards and consumer expectations for transparency and environmental responsibility. The focus on natural and clean-label ingredients (Inguglia *et al.*, 2023), coupled with the versatility of hydrocolloids across multiple sectors, positions this market for dynamic growth in the coming years.

8. Challenges and research gaps

Despite its growth and expanding applications, the hydrocolloids industry is facing several challenges and research gaps that could impact its future trajectory. The extraction and refinement of

hydrocolloids from natural sources are complex and energy-intensive, resulting in elevated production costs. Fluctuating raw material prices, especially for seaweed and plant-based sources, contribute to cost volatility and margin pressures, particularly for small and medium-sized enterprises. Many hydrocolloids are highly dependent on environmental conditions, such as ocean pollution, climate change, and overharvesting, which threaten supply stability and can lead to price spikes and shortages. Sustainable sourcing and regulated harvesting are essential to mitigate these risks. Increasing regulatory requirements related to food safety, environmental impact, and labeling create compliance challenges, and navigating diverse and evolving standards across regions can slow product development and market entry. The growing availability of alternative thickeners and stabilizers intensifies competition, particularly in markets like India.

Hydrocolloids from natural sources can vary in chemical composition, complicating standardization, quality assurance, and consistency in end-use applications, especially critical for food and pharmaceutical uses. Geopolitical tensions, trade barriers, and global events can disrupt supply chains, affecting the availability and cost of hydrocolloids worldwide. There is a need for research into more sustainable, energy-efficient, and cost-effective extraction and processing methods. It explores underutilized or novel sources, and develops advanced processing and analytical techniques. There is a significant opportunity for research into the use of hydrocolloids in emerging sectors such as pharmaceuticals, personal care, and industrial materials.

9. Regulatory challenges

The hydrocolloids industry faces numerous regulatory challenges, including strict guidelines for safety, purity, and usage levels, which increase costs and complexity for small and medium-sized enterprises. There is no universal regulatory framework for hydrocolloids, leading to logistical and compliance challenges. Labeling for hydrocolloids derived from allergenic sources is also complex, potentially limiting their use in sensitive consumer products. Environmental scrutiny and sustainable sourcing are also influencing manufacturers to provide detailed traceability and adopt eco-friendly practices. International trade disputes and tariffs can affect hydrocolloid availability and pricing, forcing manufacturers to seek alternative suppliers or absorb higher costs. Compliance with complex regulatory standards can be prohibitive for small and medium-sized enterprises, limiting innovation and competition. These challenges significantly constrain the growth and competitiveness of the hydrocolloids industry worldwide.

10. Conclusion

Hydrocolloids are essential ingredients in food innovation due to their versatility and health benefits. With the growing preference for clean-label, plant-based, and minimally processed foods, they are crucial in modern product development. They act as texturizers, stabilizers, and health-promoting agents, enabling food manufacturers to replace fats and sugars without compromising sensory quality. This makes hydrocolloids strategic at the intersection of food science and nutrition. However, further research is needed to address issues like raw material variability, regulatory compliance, and molecular interactions. Interdisciplinary collaboration is crucial for optimizing hydrocolloid applications and meeting the evolving demands of

industry and health-conscious consumers. Moreover, investigating sustainable and eco-friendly extraction and processing techniques will be crucial to meet increasing environmental and regulatory demands. Advanced biopolymer formulations combining hydrocolloids with nanomaterials or bioactive components offer promising avenues for creating next-generation functional foods, pharmaceuticals, and biodegradable packaging materials.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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