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Review

Food hydrocolloids: Functional properties, nutritional benefits and future trends

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Abstract

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Hydrocolloids represent a cornerstone material within the food industry, offering a versatile array of functionalities crucial for product development and enhancement. Their multifaceted roles encompass thickening, gelling, emulsifying, stabilizing, fat replacement, clarification, flocculation, clouding, and even whipping properties. Moreover, their utility extends beyond conventional applications, encompassing taste encapsulation, prevention of crystallization, and the formation of edible films, thus enriching the sensory and structural attributes of food products. Recent insights have illuminated hydrocolloids' burgeoning role in promoting health and wellness, particularly through their capacity to furnish low-calorie dietary fiber. This burgeoning understanding underscores their potential as functional ingredients capable of addressing evolving consumer demands for healthier food options. This review comprehensively explores the latest advancements in hydrocolloid research, delineating their diverse applications as health-enhancing agents in the food industry. By providing an exhaustive account of their utilization, the review aims to serve as a valuable resource for food scientists, technologists, and manufacturers seeking to optimize product formulations and cater to evolving consumer preferences. Given their pivotal role in improving both functional and nutritional attributes, hydrocolloids emerge as indispensable components across various sectors of the food industry. Their versatility and potential for innovation render them invaluable assets, driving advancements in food technology and facilitating the creation of products that meet the diverse needs and preferences of consumers.

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Introduction: The following study explores the multifaceted roles of food hydrocolloids, such as thickening, gelling, stabilizing, bulking, and emulsifying, across various food products, including bread, dairy, confections, and beverages [1]. Availability and quality of hydrocolloids vary due to sourcing, manufacturing, and climatic conditions, prompting ongoing research and development efforts to improve processing, standardization, and quality control [2, 3]. Companies are investing in technology to enhance solubility and reduce production time, leading to the introduction of new and improved products [4]. Expanding into health and nutritional claims supported by scientific evidence could broaden market opportunities, although many in the industry lack the resources for such endeavors [5]. Recognized as dietary fiber, hydrocolloids could contribute to recommended daily fiber intake, yet their high cost and formulation challenges limit widespread use in food products [6, 7]. Transitioning to health claims faces hurdles due to the lack of consistent human clinical trials, as highlighted by the European Food Safety Agency's evaluation [8].

Nutritional benefits of hydrocolloids: There is increase in the rising incidence of chronic illnesses like cancer, diabetes mellitus, and cardiovascular disease, often linked to the overconsumption of high-fat and high-calorie foods [9]. Concerns have also been raised about excessive carbohydrate intake, prompting recommendations from a joint FAO/WHO report to increase dietary fibre and reduce sugar consumption [9]. Understanding the nutritional benefits of hydrocolloids has grown, particularly in relation to their role in promoting vascular health through high-fibre diets, primarily due to their soluble components [10]. Guar gum, a common galactomannan found in guar seeds' endosperm, has been a focus of early research [11]. It serves as a thickening and stabilizing agent in various foods. Research from decades ago highlighted its positive effects on colon health, including delaying stomach emptying, reducing postprandial glycemia, and extending transit time from mouth to cecum [12]. However, its high viscosity and poor sensory qualities pose challenges in palatability and incorporation into enteral solutions and food preparations. Efforts to address these challenges included exploring alternative gums like cereal-glucan and attempting to lower the average molecular weight of guar gum, though this compromised its clinical efficacy [13]. Despite these challenges, many hydrocolloids are now recognized for their physiological and nutritional effects, offering potential health benefits [13].

Hypoglycemic effects and precaution against diabetes mellitus: The potential of various foods to cause a postprandial glycemic response in people varies. This reaction has been quantified using a variety of techniques, including the glycemic load and others. The GI is one of them, and it is well known for being a valid, physiologically based system for categorizing foods according to their postprandial glycemic impact [14]. According to a growing body of studies, a low GI or low GL diet can reduce the risk of type 2 diabetes, heart disease, obesity, colon cancer, and breast cancer. Diabetes mellitus is a chronic disease defined by abnormalities in glucose metabolism that lead to a hyperglycemic state and is brought on by a lack of the hormone insulin [15]. This occurs either as a result of an absolute decrease in the amount of insulin produced by the islets of Langerhans in the pancreas or as a result of a relative deficiency of insulin in patients whose tissues are resistant to the hormone. A review found that eating lower GI/GL, more readily available carbohydrate-rich meals enhances insulin sensitivity [16]. Consuming readily available carbohydrates raises blood glucose levels. Numerous factors, including hydrocolloids, affect how readily accessible carbohydrates are digested and absorbed. Guar gum appears to slow down digestive and absorption processes in the intestine, which slows down the starchy meal-induced increase in the hepatic portal vein's rate of glucose absorption [17]. Guar gel's very viscous network seems to hold onto starch pieces, preventing them from being broken down by amylase and limiting their absorption into the small intestine. It appears to have a noticeable impact. Guar gum appears to increase the fraction of bigger food particles that enter the small intestine as a result of adding it to the diet. This impact is thought to play a role in the management of diabetes, especially type 2 (insulin-dependent) diabetes [18]. It is unlikely that one mechanism will fully account for guar gum's effects on the human stomach, given the complicated behaviour of guar gum in food materials. Additionally, it has been hypothesized that a rise in the viscosity of the digestive fluid will result in laminar rather than turbulent flow. A measure of how quickly starch pieces reach the epithelial surface and are then taken up by the hepatic portal vein would be impacted by laminar flow behaviour [19]. Guar gum is believed to treat diabetes through improving insulin sensitivity in addition to the previously discussed mechanism. Numerous scientific studies have focused on the connection between diabetes and other hydrocolloids more recently. The majority of physiological investigations on oat -glucan concentrated on the reduction of insulin and blood sugar reactions in both healthy and diabetic people [20]. Some focus on glycosidase, which is a popular target for the creation of anti-diabetic medications. Oat -glucan has the potential to block the -glycosidase (sucrase and maltase) enzyme and can significantly alter the internal environment of the digestive tract. On the other hand, numerous researches examine whether oat-glucan may modify starch digestibility and, as a result, affect its bioactivity in decreasing glycemic reactions [21]. Although Artemis sphaerocephala Krasch. seed is not well known to us and is not employed in the food sector, practitioners of traditional Chinese medicine long ago recognized that the seed can be used to cure diabetes. ASK gum was isolated from A. sphaerocephala Krasch, and it was tested for its antioxidant effects on type 2 diabetes in Sprague-Dawley rats that had been induced with the disease using the drug streptozotocin. The results showed that giving the diabetic rats ASK gum considerably raised their liver and serum SOD activity while also dramatically lowering their MDA and OH levels [22]. In addition, ASK gum significantly reduced the kidney oxidative damage in the diabetic rats. It should be mentioned that the particular mechanism by which hydrocolloids prevent diabetes is still unknown, and that the reason for this is that researchers currently have a limited understanding of the activity of hydrocolloids in the human gastrointestinal system [23].

Prebiotic effect: Since bifidobacteria, lactobacilli, and Streptococci thermophilus are thought to have a variety of health effects and possibly protecting against intestinal diseases, hydrocolloids have received a lot of attention [24]. These bacteria are commonly referred to as probiotics, and theoretically, probiotics are living microorganisms that have positive impacts on host health when taken in the right amounts [25]. Prebiotics is a word that has received significant media attention as a healthy food intervention. Prebiotics are non-viable food ingredients that promote the health of the gut microbiota and boost defences against pathogenic organisms [26]. A food ingredient may be classified as a prebiotic if it meets the following criteria:

1) In the upper gastrointestinal tract, it must not be hydrolyzed or absorbed.
2) It must be specifically fermented in the colon by a few potentially advantageous bacteria.
3) It needs to change the intestinal microflora's makeup.
4) It must, whenever possible, enhance the host's health.

The most extensively studied and well regarded prebiotic in the hydrocolloid family is inulin, which is classified as food or a component in food in every country where it is consumed [27]. Inulin's (2-1) glycoside bonds have been found to be resistant to hydrolysis by human small intestine enzymes. Inulin succeeds in avoiding digestion in the upper gastrointestinal system and making it to the large bowel unaltered. It has been proven that inulin's prebiotic action can alter the gut immune system when paired with the probiotics Lactobacillus rhamnosus and Bifidobacterium lactis [28]. The relationship between hydrocolloids and gut health, particularly focusing on their interaction with beneficial bacteria like bifidobacteria, lactobacilli, and Streptococcus thermophilus, commonly known as probiotics [24]. Probiotics are live microorganisms that can confer health benefits when consumed in adequate amounts [25]. On the other hand, prebiotics are non-viable food ingredients that support the growth of beneficial gut bacteria, aiding in defense against harmful organisms [26]. Investigated were the roles of immune cells that had been isolated from Peyer's patches (PP), spleen, mesenterial lymph nodes, and peripheral blood mononuclear cells (PBMC). These experiments demonstrated that inulin largely affected the lymphoid tissue in the gut. [29] discovered that fermentation byproducts may have helped to modify colon morphology and mucin (MUC)-3 gene expressions in post-weaning rats in addition to affecting the microbiota composition [29]. On the other hand, colon's prebiotic response to inulin Although bifidobacterium is well recognised, in vivo stimulation studies frequently ignore interspecies variations by concentrating on the bifidobacterial community as a whole. In a recent study, the ability of these strains to compete for inulin in a coculture with a B. thetaiotaomicron strain that degrades inulin was investigated [30]. Although prebiotics have several benefits in terms of physiological processes, inulin fermentation's negative effects must also be taken into consideration. The gases are byproducts of fermentation that are unavoidable, but in certain levels, they can cause uncomfortable symptoms like cramps, borborygmi, and flatulence [31]. Therefore, gastrointestinal tolerance, sometimes referred to as intestinal acceptance of prebiotic, has been studied recently.

Ameliorating constipation: Constipation strains the lower abdominal muscles and causes persistently high intestinal lumen pressures, which raises the chance of developing muscular degeneration [32]. Psyllium seed, which is grown all over the world but is most common in Iran and India, is commonly employed in the pharmaceutical and food industries. Psyllium, a hydrocolloid derived from psyllium seeds, is a kind of arabinoxylan. Psyllium is hydrophilic, fibrous, and produces a translucent, colorless mucilaginous gel by absorbing water [33]. the use of psyllium seed and other hydrocolloids as laxatives to alleviate constipation. Psyllium, derived from psyllium seeds, is a hydrophilic, fibrous substance that forms a translucent, colorless mucilaginous gel when it absorbs water [33]. This gel property enables psyllium to bulk up stool, making it easier to pass. After ingestion, psyllium multiplies and produces a gel-like substance in the colon, which increases both the weight of feces and stool output [34].

Unlike psyllium, which resists bacterial digestion and remains more laxative, guar gum is swiftly broken down by colonic microorganisms and has little impact on stool output [23]. However, even partially fermented hydrocolloids can enhance stool production by retaining water, as residual water-holding capacity is sufficient to boost stool volume [23]. Additionally, non-therapeutic gums like gellan, produced by bacteria, have been found effective as stool bulkers [33]. Slowly fermented gums such as xanthan and karaya gum may increase fecal short-chain fatty acids (SCFA) and stool moist weight without significantly affecting stool solids [33]. The literature has documentation on the gel property. Because of its bulking properties, psyllium has been suggested as a laxative to treat constipation. After eating, it multiplies and produces a colonic gel-like substance [33]. It proved that the weights of the latter and feces both increased in response to psyllium absorption. Four hours after ingestion, the majority of the psyllium had formed a gel and was in the caecum [34]. The generation of feces and the ability to hold water were long thought to be inversely related. Unlike to psyllium, which is more laxative and resists bacterial digestion, guar gum has little impact on stool output since it is swiftly broken down by colonic microorganisms. In fact, a hydrocolloid's residual ability to hold water may be sufficient to boost stool production if it is just partially fermented [23]. The non-therapeutic gum gellan generated by bacteria has also been praised for its effectiveness as a stool bulker. The generation of fecal SCFA and stool moist weight may increase in response to several slowly fermented gums, including xanthan and karaya gum, without increasing stool solids [33].

Prevention of colon cancer: The gastrointestinal system is undoubtedly at the vanguard of hydrocolloids' nutritional effects, and modulating colon activity is a particularly intriguing field of study [34]. The modern understanding of colonic functions includes processes that influence the in situ proliferation of pathogens, such as the body's defence against the movement of bacteria, the regulation of intestinal epithelial cell development and proliferation, endocrine and immunological activities, and the generation and absorption of fermentation by products like short-chain fatty acids. If the colon is malfunctioning, serious illnesses will show up, ranging from acute infections (diarrhoea or constipation) to chronic conditions like inflammatory bowel diseases (IBD), irritable bowel syndrome (IBS), or colon cancer [56]. According to Ranji *et al.* (2015), colon cancer is the second most prevalent cancer-related death, and dietary habits are linked to the control of colon carcinogenesis [57]. A few decades ago that the absence of colon cancer in Africa was due to the high-fibre diet of Africans. Since then, dietary fibre has been proposed to reduce colonic pH, adsorb or dilute faecal carcinogens, shorten colonic transit time, alter bile acid metabolism, or increase the formation of short-chain fatty acids to prevent colon cancer [35]. Inulin and other types of fructans (levan) have received increased interest as dietary fibers that can protect against colon cancer. Consuming inulin or other prebiotics is linked to anticarcinogenic effects, one of which is the gut's ability to detoxify genotoxins. As was already said, when inulin is administered, SCFA are produced, and butyric acid, which feeds the colonic mucosa, serves as the colonic enterocyte's main source of energy [36]. According to some research, butyric acid encourages cell differentiation, cell-cycle arrest, and apoptosis in colonocytes that have transformed. As is well known, colonic cell proliferation is thought to grow as a risk factor for cancer. However, apoptosis, a tightly controlled mechanism, gives every cell in the colon a set time to die. The equilibrium of levels of apoptosis and proliferation likely determines whether or not a tumour will develop. Butyrate has been demonstrated to promote the growth of healthy colonic cells, but it has also been shown to promote apoptosis in cancer cells *in vitro* [55]. Additionally, it might influence other deadly stages of carcinogenesis, like encouraging a reduction in the conversion of primary to secondary bile acids and inhibiting histone deacetylase, which might encourage DNA repair. Constipation causes the colonic epithelial cells to be exposed for a lengthy period of time to mutagenic substances, which may lead to colorectal neoplasia. Therefore, any hydrocolloids that have the ability to encourage faeces could be beneficial for colon cancer. Inulin must be given far in advance of exposure to the carcinogen, not just before, in order to successfully prevent colon cancer [37].

Future trend food hydrocolloid study:

The future trend of hydrocolloids study was depicted in figure 1.

The mechanism and regulation of the interaction of food hydrocolloids with food components:

Food hydrocolloids which make up the skeleton of food, are regarded as essential elements that have a substantial impact on food processing, sensory perception, nutrition, and stability [38]. However, it is still unclear how food hydrocolloids interact with one another and with other food components on an intrinsic level. Furthermore, little is known about the many sizes at which these interactions are controlled. Thus, there is an urgent need for systematic and thorough studies on these pertinent themes [38].

Structuration of food colloids and future food structure design:

People are becoming more concerned about the nutritional value and health advantages of food products together with continuously improving life quality [39]. Future food products must be created in a way that can satisfy the unique dietary and health requirements of many communities. Food colloids are crucial for creating the food structures of the future. Future food structures can be created by structuralizing food colloids and examples include functional foods for the elderly with swallowing difficulties, foods specifically formulated for people with diabetes, and vegetarian artificial meats made from plant sources [40].

The interaction of food colloids with human body and its influence and regulation effects on the nutritive functions of foods

The study of food science and technology is being pushed deeper and deeper into a "in-body" age that emphasises how food components are altered inside the body because of its inter-disciplinarity with life science and medicine [41]. In-vivo colloidalization is another name for the process of food digestion and absorption, and the in-vivo colloidal form of food elements has a significant impact on how well they digest and absorb nutrients. As a result, it was assumed that some food colloidal particles would be able to be absorbed in their entire particle structure without being broken down by the digestive system. For instance, nano-colloidal particles can be directly absorbed by digestive epithelium cells. The specific biological results and subsequent physiological effects of these food colloids, as well as their routes of absorption, are unknown [42]. The interaction of food colloids with the human body and relevant signal transmission, the mobility of colloidal particles inside the body and the cells, and their regulation mechanisms will thus be the major essential scientific concerns in the future study of food science and technology. With the intention of appropriately positioning and promoting the achievements in these significant problems, which are often covered by nutriology-related food colloids, we termed this new field of study "Food Colloidal Nutrition" [43].

***In-vivo* metabolism and safety evaluation of food colloids:**

The *in-vivo* safety of nano-colloidal particles has long been a topic of discussion. Some synthetic nanoparticles can build up inside the body and cause cytotoxicity, tissue damage, and organ toxicity [44]. As a result, they are seen as enormous concealed risks that pose a danger to human health. Nano-colloidal particles, which are the building blocks of food flavour and health benefits, are always introduced during the traditional food preparation and processing processes [45]. As a result, one of the most crucial research areas will be the *in-vivo* metabolism characteristics and safety of food colloids, which will require systematic and impartial investigation in the future.

Source and classification of food hydrocolloids:

Hydrocolloids are a family of dietary polysaccharides that have a wide range of structural variations. While chitin and chitosan from animals are also widely used in the food industry, the majority of naturally occurring hydrocolloids come from plants, such as terrestrial plants and seaweeds [46]. Bacterial cellulose, xanthan, dextran, pullulan, and curdlan are just a few examples of the diverse secondary metabolites that microorganisms produce in addition to animal and plant-derived polysaccharides [46]. These compounds have a variety of physicochemical properties as well as additional structural and metabolic functions. While plant sources make up the majority and are the least expensive among other groups due to their minimal processing requirements, synthetic hydrocolloids, on the other hand, are the most expensive if manufactured from expensive materials using sophisticated technology. Based on where they came from, hydrocolloids are separated into four major groups:

1. Hydrocolloids produced from plants
2. Hydrocolloids generated from animals
3. Hydrocolloids derived by microorganisms (Fermentation)
4. Hydrocolloids produced from plants but chemically altered (synthetic gums)

According to their biological source, hydrocolloids are grouped in Figure 2 in an overview. These biopolymers differ significantly structurally in terms of their chain length and branching properties. This hydrocolloid solution is extremely viscous but unstable [1]. Dextrans belong to a different family of hydrocolloids with a single branch that contains sugar units that have carbon groups other than C1 or C4 condensed in them. One sugar unit in length and several substituted short branches are the distinguishing features of guar gum, also known as locust bean gum [43]. Furthermore, branch-on-branch solutions with lower viscosity but greater stability than linear ones are a distinguishing feature of gum arabic, amylopectin, and tragacanth gum. Excellent adhesive characteristics can be seen in these hydrocolloids [44]. Additionally, as they can be neutral or ionic, the charge of the biopolymer is thought to be an important factor in their classification. By strengthening their attraction for water molecules and impeding intermolecular interactions, the charged groups contribute to the solubility of the compounds. Another useful method of categorizing hydrocolloids is based on the presence of monomeric units in their chemical structure, which would be classified as homoglycans, heteroglycans, tetra-heteroglycans and penta-heteroglycans [38]. Thus, the overall classification is based on the chemical composition, ionic potential, source, and shape of the substance

Hydrocolloids in Nano-drug delivery applications:

The scientific community has been concentrating on research into the use of food colloids in the production of nanocarriers for regulated and target specific medicine delivery due to the public's revived interest in bio-based natural substances [45]. This is because these materials have excellent biological properties, low toxicity, and are biocompatible. The drug molecules' pharmacokinetic properties and effectiveness of encapsulation are improved by the nano-carriers, which also inhibit drug degradation [46]. Nevertheless, drug distribution regulates the release of drug, prolongs them *in-vivo* action, lowers drug metabolism, and lessens a medication's toxicity. The three primary natural food colloids employed in various nano-delivery systems are proteins, polysaccharides, and lipids [47]. Each form of biopolymer has advantages and disadvantages relative to other types of biopolymers. For the encapsulation of various medications and nutrients, proteins with amphiphilic characteristics are better candidates for designing nanoparticles. However, these proteins have low thermal stability because They are susceptible to external stressors in their secondary and tertiary structures. Moreover, due to their great sensitivity to pH fluctuations and digestive enzymes, they are not suitable for oral delivery [48]. Although polysaccharides lack secondary and tertiary conformation and have simpler structures than proteins, they still have a relatively high molecular weight, which leads to a large particle size. Moreover, their propensity to form nanoparticles for the encapsulation of lipophilic substances is typically constrained by their high hydrophilicity. When made into nano-emulsions and liposomes, lipid-based nanoparticles are highly hydrophobic or amphipathic small molecules ideal for encasing lipophilic bioactive compounds, but one of their main drawbacks is their insolubility in a liquid media [49]. The nanoparticles produced this way from a single biopolymer do not have the necessary properties to be used in oral administration systems. Binary and ternary biopolymer (protein-polysaccharide) mixes, which are typically composed of two proteins and one polysaccharide, can be used to create nano-complexes [50]. The main difficulty in creating ternary nanocomposites, in contrast to protein nanoparticles or nano-emulsions, is that they have very after the third biomaterial is put as the top layer, huge dimensions (150-200 nm). To address this issue, biopolymer nano complexes can be physically encapsulated or covalently conjugated onto a matrix, like chitosan-based hydrogel beads, to improve control release qualities and stop digestion-enzyme-induced disintegration/degradation, resulting in improved gastrointestinal stability and biological efficacy without expanding in size [51]. The cross-linking of hydrophilic polymers creates a three-dimensional network of hydrogels with desired properties for distribution applications, including enhanced larger polymer chains, increased surface area, reduced crystallinity, increased porosity, and easier access to internal absorption sites [52]. Several hydrocolloids have proven to have potential in the pharmaceutical industry for preserving and shielding pharmaceuticals against environmental stressors. Guar gum (GG) is a perfect vehicle for delivering colon-specific medications due to its inherent gelling capabilities, pH-responsive behaviour brought on by Ionic groups make up its structure, and the large intestine is susceptible to bacterial and enzyme-induced degradation [34]. The matrix, compression-coated pills, and other products have all made use of this polymer that dissolves in water, nanoparticles, and hydrogels. In addition, extensive study suggests that guar gum is used in transdermal drug delivery systems, antihypertension medications, and protein. However, the main restriction on its application is connected to its strong swelling qualities, which result in the quick release of drug molecules that have been loaded into them. The authors found that bovine serum albumin and lysozyme released rapidly at first, then slowly over the course of 24 hours [53].

Similarly, chitosan, the only positively charged polysaccharide, is the most versatile and non-toxic natural polymer for application in drug delivery systems [54]. An excellent targeted molecule for the therapy of advanced metastatic cancers is folic acid (FA), making it a great drug carrier when used to target colorectal cancer in particular. However, due to a poor conjugation ratio and low targeting effectiveness, folic acid does not attach effectively to all polymers. As a result, the 1,3-diamino propane cross-linker was used to further increase the FA's effectiveness. This cross-linker improves FA conjugation (46.7%), which increases nanoparticle cytotoxicity and makes it easier to deliver drugs specifically to the target cells in the HT-29 cancer cell line [55]. Manzoor and associates have shown that cross-linking basil seed gum (BSG) with calcium ions or another divalent cation can form a pH-responsive drug delivery system for glutathione [38]. This nanoparticle has an encapsulating efficiency of 88.29% and a potential use for medication administration in the treatment of tumors. In a separate work, nano-micelles made of amphiphilic polymers based on konjac glucomannan were synthesized and tested as a viable nano-drug delivery system for intracellular curcumin [3]. The KGM-g-AH8 conjugate self-assembles into spherical nanoparticles with a high curcumin loading capacity, measuring 107.6 nm in size. This improves the model medicine (curcumin) for cancer therapy's effectiveness [43].

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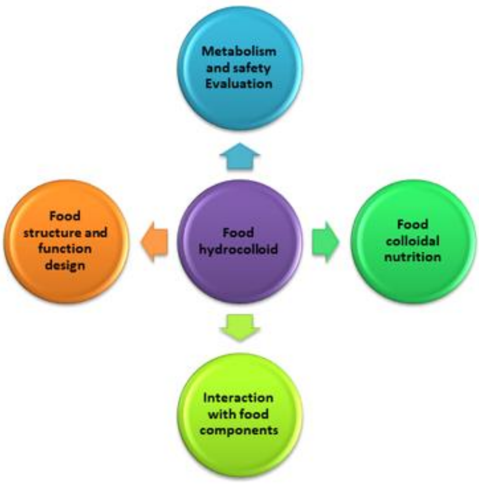

Figure 1. (Future trend of Hydrocolloids)

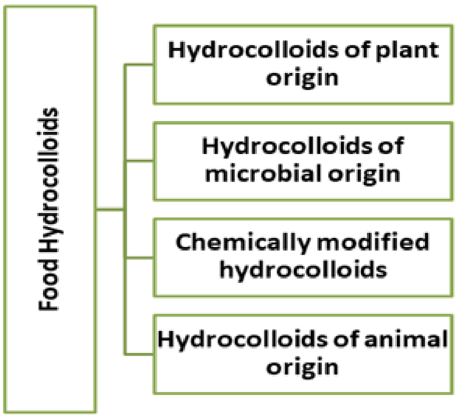

Figure 2. (Groups of hydrocolloid)