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A comprehensive review on food hydrocolloids as gut modulators in the food matrix and nutrition: The hydrocolloid-gut-health axis

ABSTRACT

Background

Food hydrocolloids are versatile natural food ingredients, which can be authentically present in food matrices or can be added as functional food ingredients and/or food additives. All hydrocolloids are common in industrial use with enhancers of viscosity, emulsifiers, coating, gelling agents, stabilizing agents and/or thermodynamic stability providers. While safety issues of hydrocolloids in the food industry have been discussed until now, research has turned to their effects on gut modulation, human health and wellbeing.

Scope and Approach

This review focuses on a comprehensive discussion of certain food hydrocolloids in gut modulation and their potential interaction with health through gut modulation.

Key Findings and Conclusions

Novel literature suggests that certain food hydrocolloids could substantially change the range and structure of the microbiota of the gut and the primary bioactive metabolites. Besides, hydrocolloids show important outcomes on gut microbiota because of their physicochemical and structural properties. Moreover, they may have various impacts, and the mechanisms of gut microbiota activity are quite diverse depending on their polymeric structure and source. Despite some discrepancies and divergences in their impacts on the gut microbiota-health axis, their reassuring outcomes on health are mainly associated with their prebiotic or prebiotic-like effects. In this way, it can directly/indirectly affect host health. Therefore, while investigating the possible health and safety effects of the use of hydrocolloids in the form of food additives, it may be useful to investigate the benefits and side effects on the gut.

Keywords: food hydrocolloids, gut modulation, prebiotic, microbiota

1. Introduction

In the modern world, technology has reached its peak and thus is in a period of important advancements in food technology development as well as in the nutrition-health awareness of consumers. Thus, so far, the food industry has had endeavours to offer consumers high-quality rheological properties along with health-full and nutritious food products (Goff & Guo, 2019; Manzoor, Singh, Bandral, Gani, & Shams, 2020). As a result, there has been wide use of food hydrocolloids in the formulation/reformulation in a range of food categories, functional food production in addition to innovation initiatives in recent years (Manzoor et al., 2020).

The term hydrocolloid, mainly employed in the food industry, is described as a colloid structure in which molecules are hydrophilic polymers dispersed in water (Hollingworth, 2010). Food hydrocolloids are considered as crucial food components owing to their improvements to viscosity, gelation, as well as thickening; improving the rheology and sensory food-properties (Dipjyoti Saha & Suvendu Bhattacharya, 2010; Goff & Guo, 2019). Gum and mucilage terms can also be used as synonyms for hydrocolloids infrequently. Regardless of what they are called, these ingredients are generally found in industrial applications as enhancers for viscosity, emulsifiers, coating, gelling agents, stabilizing agents, and thermodynamic stability providers (Goff & Guo, 2019; Maity, Saxena, & Raju, 2018; Manzoor et al., 2020) **(Figure 1).** They are mainly applied functionally in food products including confectionery (coating agents, texturizing), specific beverages (emulsifiers), dairy based products (thickeners and stabilizers), pastries (bulking agents, sensorial quality and shelf life enhancer), frozen fruits and vegetables (cryoprotectant) (Maity et al., 2018; Salehi, 2020; Viebke, Al-Assaf, & Phillips, 2014). Lately, food hydrocolloids have reached the leading edge with their health advantages as well as relevant pharmaceutical applications along with food applications. Besides, the possible health effects and mechanisms of their dietary intake-processes are under more discussion nowadays (Viebke et al., 2014).

Recent literature has indicated that food hydrocolloids display crucial roles on gut microbiota due to their different physicochemical or structural properties (Tan & Nie, 2021). Some of these important roles are their prebiotic impacts, stimulating to produce short-chain fatty acids (SCFAs), declining gastro-intestinal discomfort in addition to preserving normal bowel function (Marciani et al., 2019; Viebke et al., 2014; Williams & Phillips, 2021), an increase in the viscosity within the intestinal lumen, reduction or increase in certain nutrient absorption (Nybroe et al., 2016), lower cholesterol (Manzoor et al., 2020; McClements, 2021), a decline in hyperglycemia (Lu, Li, & Fang, 2021) as well as normal body weight regulation (Johansson, Andersson, Alminger, Landberg, & Langton, 2018; Viebke et al., 2014). Besides, the research on hydrocolloids along with gut modulation appears to spread day by day due to the cutting-edge multi-omics technologies as well as the detailed-oriented analysis of the human microbiome. This article provides a comprehensive review on specific food hydrocolloids especially those have the structure of polysaccharides in gut modulation along with their potential interactions with nutrition and health.

2. Gut microbiota alteration/modulation of food hydrocolloids

Food hydrocolloids affect gut microbiota in various ways, and their action mechanisms are quite diverse. Regarding this diversity, the impacts of hydrocolloids on gut modulation are summarized in **Figure 2**. In this respect, its modulatory effects are commonly associated with prebiotic activities. The indigestible structure of hydrocolloid polysaccharides is often associated with their prebiotic activity. **Table 1** compiles the prebiotic activity of diversified hydrocolloids that are prevalent. Firstly, most hydrocolloids are resistant to gastrointestinal digestion. Secondly, they can easily be fermented into SCFAs. Thirdly, they operate as selective fermentable substrates of probiotic bacteria. Fourthly, they inhibit the pathogenic bacteria by decreasing pH during the fermentation period. During this fermentation process, SCFAs may inhibit pathogenic bacteria by reducing pH levels (Gannasin, Mustafa, Adzahan, & Muhammad, 2015), while increasing the number of beneficial bacteria such as *Bifidobacterium* and *Lactobacillus*, which have a potential effect on plasma lipids and satiety (Manzoor et al., 2020). Finally, they may lead to enhancement in the composition of gut microbiota by decreasing dysbiosis (Manzoor et al., 2020; Praveen, Parvathy, Jayabalan, & Balasubramanian, 2019). On the other hand, since the fermentation of dietary fiber like certain hydrocolloids produces gases, mainly CO_2, H_2 and CH_4, diets rich in rapidly fermentable dietary fiber cause bloating and abdominal symptoms. Therefore, diets containing both fast and slowly fermentable dietary fiber should be considered in balance to optimize the health effects of gut microbiata activity (Yao et al.,2023)

One of their advantages on the bowel is reduced gastrointestinal discomfort and maintanence of normal bowel function. They achieve this effect through increased bowel movement and shortening food transit time. Hydrocolloids may be used by some of the microorganisms of the gut microbiome to produce SCFAs for improved intestinal comfort and delay colonic fermentation, as shown by the rate of gas pressure evolution (Rosa-Sibakov et al., 2016). They also lessen constipation owing to their fecal bulking and water-retention effects (Williams & Phillips, 2021).

Food hydrocolloids boost solubility and viscosity (gelling ability) in the intestinal lumen. They expand intestinal viscosity, lead to modified enzyme activity and micelle formation. Thus, they modulate nutrient absorption (Nybroe et al., 2016). They block the intestinal process of absorbing glucose by binding absorbed carbohydrates into a very viscous network and by reducing the accessibility of the enzymes -amylase and -glucosidase (Lu et al., 2021; Wu, Shi, Wang, & Wang, 2016). They also reduce cholesterol levels by averting the reabsorption of bile acids in addition to the absorption of cholesterol and fatty acids in the intestinal lumen (Manzoor et al., 2020; McClements, 2021). It has also been reported that hydrocolloids may be effective for body weight loss. A possible mechanism for this impact is induction satiety and reduced energy intake as a result of delays in gastric emptying (Johansson et al., 2018; Viebke et al., 2014). Due to all these gut-mediated effects, some colloids may have potentially beneficial effects on human health under certain conditions (**Figure 2**).

2.1. Molecular Mechanism of Hydrocolloids on Gut

Functional hydrocolloids promote gut microbiome metabolism, and intestinal bacteria produce complex structural molecules and metabolites that activate multiple signaling pathways associated with various target tissues/organs (Figure 3).

Certain hydrocolloids especially those of assuming dietary fibers are not digested in the upper gastrointestinal tract and hydrolyzed by enzymes secreted by the bacteria residing in the colon. One of the primary fermentation products arising from the digestion of hydrocolloids especially those of assuming dietary fibers and source of dietary fibers is short-chain fatty acids (SCFAs), such as acetate, propionate, and butyrate. The main mechanism of these food hydrocolloids is to stimulate to production of SCFAs in the gut. SFCAs act as a fuel source for the colonic enterocytes, as well as signaling molecules with the host. This is the reason why they may be important in keeping the gut healthy. The type and amount of SCFAs produced in the gut affect the gut microbiota composition, which plays a crucial role in human health and well-being (McClements, 2021).

The immune system has been shown to be affected by SCFAs, which can lower the risk of infammatory diseases, type 2 diabetes, obesity, heart disease, and other symptoms including cancer (Ríos-Covián et al., 2016). For instance, butyrate can induce Treg differentiation and increase the generation of Th1 and Th17 cells (Al-Qadami et al., 2022; Corrêa-Oliveira et al., 2016). Besides, SCFAs, whose production are stimulated by certain food hydrocolloids boost to increasing the number of beneficial microorganisms in the gut, thanks to acting as a fuel source and decreasing pH levels (Portincasa et al., 2022, McClements, 2021). Beneficial microorganisms increased by hydrocolloids in the diet may modulate inflammation by controlling immune pathways and competing with infectious pathogens. *Eubacterium eligens* and *Faecalibacterium prausnitzii*, which are likely to be stimulated by pectin, guar gum, and modified starch, were able to stimulate adequate anti-inflammatory IL-10 in human peripheral blood mononuclear cells and colitis. (Breyner et al. 2017). Structural molecules of commensal bacteria, such as polysaccharide A (PSA) and sphinogolipids from *Bacteroides fragilis*, which can be potentially promoted by pectin, participated in inflammation modulation by promoting IL-10 producing CD4+ T cells and downregulating IL-17 (Round et al. 2011) and suppressing the over activation of the invariant natural killer T cells during infection, respectively (An et al. 2014). The formation of cancer has previously been connected to SCFAs, and the literature have demonstrated that butyrate, propionate, and acetate induce death in cancer cells but not in healthy cells (Al-Qadami et al., 2022). The immunomodulatory properties of SCFAs, which can change anti-tumor effects including levels of tumor-killing CD4+ and CD8+ T cells, as well as immune-suppressing Tregs, are crucial for this (Al-Qadami et al., 2022). Pectin can improve human health by controlling certain pathways that may be activated by oxidative stress and inflammation, including the AMP-activated protein kinase (AMPK), nuclear factor erythroid 2-related factor-2 (Nrf2), and nuclear factor-B (NF-B). The activation of these signaling pathways increases the antioxidant and antiinflammatory activities, which will result in the apoptosis of cancer cells. Pectin may thereby prevent the growth of cancer through influencing the antioxidant and anti-inflammatory signaling pathways AMPK, Nrf2, and NF-B (Tan et al., 2018). Therefore, hydrocolloids may be effective in maintaining bowel health and preventing bowel cancer (Tan et al., 2018; Al-Qadami et al., 2022).

Hydrocolloids in the diet such as pectin, gum arabic, guar gum, and modified starch correlate strongly with the production of colonic SCFAs. Their SCFA metabolites and *Bifidobacterium breve* ameliorated chronic stress by regulating cFOS and brain-derived neurotrophic factors (BDNF) in the hippocampus and intestinal 5-hydroxytryptophan (5-HT) (Tian et al., 2020). Therefore, hydrocolloids may contribute to the improvement of depression and anxiety by affecting the central nervous system in brain.

Butyrate and propionate can reduce blood pressure and decrease the risk of cardiovascular diseases. It is suggested that propionic acid ameliorated cardiovascular injury by inhibiting splenic Th-17 cells and thereby reducing immune cell infiltration in the heart (Bartolomaeus et al., 2019). Thanks to these effects, hydrocolloids can be effective on such as hypertension, heart failure, atherosclerosis. Furthermore, *Bifidobacterium lactis* and *Lactobacillus plantarum* and major SCFA products were capable of improving non-alcoholic fatty liver diseaserelated insulin resistance, dysfunction of hepatic lipid synthesis and intestinal inflammation (Zhao *et al.* 2020). In addition, microbe-derived secondary bile acid helped the repression of lipogenesis-associated gene transcription in liver via upregulating AMPK and downregulating NF-kB (Petrov *et al.* 2019).

Metabolic dysfunction is linked to disturbed gut microbiota diversity and *Firmicutes/Bacteroidetes* ratio and can be alleviated by specific bacterial isolates and their metabolites linked to cellular mechanisms involved in energy metabolism, insulin sensitivity, bile acid circulation, and appetite signaling (Tan and Nie, 2021). SCFAs play a role in regulating many pathways such as the activation of G-protein-coupled receptors (GPCRs) and stimulation and inhibition of histone deacetylase (Tingirikari, 2018). G-protein-coupled receptors on the surface of colonocytes, liver, and skeletal muscle cells detect SCFAs and stimulate them to become active (GPR 41, 43 and 109a). For instance, GPR 43 activates L-cells of the gastrointestinal tract to secrete the gut hormone peptide YY (PYY) and glucagon-like peptide-1 (GLP-1). PYY levels rise when food is consumed, whereas GLP-1 works as a significant antihyperglycemic hormone and triggers the release of insulin from pancreatic beta cells in response to an increase in blood glucose levels. (Maslowski et al., 2009). In this way, it can reduce food intake by stimulating the feeling of satiety. Succinic acid from *Parabacteroides distasonis* protected insulin sensitivity from a high-fat diet through intestinal gluconeogenesis (Wang et al. 2019) or uncoupling protein (UCP) 1-dependent thermogenesis in brown tissue and fat storage (Mills et al. 2018). Also, SCFAs alter metabolic rate by stimulating GPR43 in adipocytes. For this reason, it is thought that hydrocolloids may have effects on increasing energy expenditure and improving glucose tolerance to increase energy utilization (Kimura et al., 2014).

3. Specific food hydrocolloids and their gut microbiota alterations/modulation

Hydrocolloids are mostly food polysaccharides classed as food components although some of them are not polysaccharides (Xi Yang, Li, Li, Sun, & Guo, 2020). Based on their sources, they fall into four main categories and are often utilized in the food industry: i) hydrocolloids of plant origin, ii) hydrocolloids of animal origin, iii) hydrocolloids collected from microbial origins (fermentation), and iv) plant-derived hydrocolloids which are chemically modified (synthetic gums). **Figure 4** indicates the classification of hydrocolloids, which are categorized according to their biological origins and whose main prebiotic effects on the gut microbiota are examined in this review (Li & Nie, 2016; Manzoor et al., 2020).

3.1. Plant exudates

3.1.1. Gum Arabic/acacia gum

Acacia gum, which is also referred to as gum arabic, is a soluble secretion found on *Acacia Senegal* as well as *Acacia seyal* trunks and branches (Alnadif, 2018). This gum type is commonly used in the food, pharmaceutical, and cosmetic industries owing to its emulsification, encapsulation, stabilization, and adhesion properties which are technologically important and are correlated with the structural properties of both the acacia gum as well as its components (Grein-Iankovski et al., 2018). Acacia gum mainly consists of highly branched polymers of galactan, galactose and/or arabinose side chains, and long-chain complex polysaccharides including rhamnose or glucuronic acid as termination residues (Rawi, Abdullah, Ismail, & Sarbini, 2021).

A highly assuring application of acacia gum is its application as a prebiotic due to its resistance to digestive enzymes in the small intestine (Calame, Weseler, Viebke, Flynn, & Siemensma, 2008; Rawi et al., 2021). A human study revealed that consuming gum arabic at a dose of 10 g/day within the period of 4 weeks is correlated with higher amounts of *Bifidobacteria* and *Lactobacilli* in stool samples compared with water (negative control). The study further indicated that the number of *Bifidobacteria*, *Lactobacilli,* and *Bacteroides* substantially increased after gum arabic intake compared with 10-g inulin intake (positive control). The outcome of the same study indicated that gum arabic may be recognized as a prebiotic fiber with at least as much functionality as inulin (Calame et al., 2008). An *in vivo* study assessed the effect of administering *Lactobacillus plantarum* MBTU-HK1 as a probiotic and acacia gum as a prebiotic alone or in combination (as a synbiotic). It was discovered that consuming these as a symbiotic had a number of health-enhancing properties, including reducing blood lipid levels, immune function regulation, and reduction in the level of carcinogen-releasing enzymes (Chundakkattumalayil, Kumar, Narayanan, & Thalakattil Raghavan, 2019). As a prebiotic source, in an *in vitro* colon model inoculated with human fecal microbiota, acacia gum inhibited the *Clostridium histolyticum* group, which is generally associated with gut dysbiosis. It also promoted *Bifidobacteria* proliferation, similar to fructooligosaccharides (FOS). Thus, it is stated that acacia gum is protective against gut dysbiosis as it supports microbial population modulation in addition to SCFA production through butyrate and gut probiotics specifically (Rawi et al., 2021).

Conflicting changes observed in gut microbiome composition, SCFAs plasma levels and biochemical markers of kidney function in rats with chronic kidney disease brought about by dietary adenine were attenuated by gum arabic (Al-Asmakh et al., 2020). However, there is a requirement of more randomized-controlled clinical studies to reveal its positive effects on different diseases.

3.1.2. Tragacanth gum

As an anionic polysaccharide, tragacanth gum (TG) is a biobased polymer obtained from continual resources (Taghavizadeh Yazdi et al., 2021; Zare, Makvandi, & Tay, 2019). It is generally obtained from the stems and branches of the “carob” plant (Astragalus sp.) located in the mountainous regions of Southwest Asia (Ghaderi-Ghahfarokhi, Yousefvand, Ahmadi Gavlighi, Zarei, & Farhangnia, 2020; Taghavizadeh Yazdi et al., 2021). Due to its thickener, emulsifier, and stabilizer properties, it is used in a wide range of fields in industries including food, pharmaceutical, textile, cosmetics and other industries (Hatami, Nejatian, & Mohammadifar, 2012). Tragacanth gum shows prebiotic properties (Ghaderi-Ghahfarokhi et al., 2020; Yu et al., 2021). In a recent study, the possible prebiotic effects of inulin, natural TG, and the pectinase hydrolysed fraction of tragacanth gum (PHFTG) on *Lactobacillus casei* in low-fat yogurt were compared. Natural TG displayed weaker volume in addition to structure, lower sensory acceptability and more syneresis compared to the others, while the sensory acceptability of *Lactobacillus casei* PHFTG and *Lactobacillus*-inulin groups was discovered as higher and the syneresis of the same group was found to be lower (Control - without both *Lactobacillus casei* and prebiotic and compared with the group containing only *Lactobacillus casei*). It has also been concluded that PHFTG may be applied as a potential replacer for prebiotic and fat in skim or low-fat dairy products with sensory quality (Ghaderi-Ghahfarokhi et al., 2020).

3.1.3. Pectin

Pectins are composite polysaccharides, which are often detected in the primary walls of plants. The major role of plant cell wall components is to mechanically strengthen plants, protect the extracellular water phase through absorption, and build a barrier against the external environment (Leclere, Cutsem, & Michiels, 2013).

Currently, the majority of commercial pectin is obtained through citrus (lemon, lime, orange) peels (85.5%), while a limited portion is obtained from apple fiber (14.0%) and sugar beet fiber (0.5%) (Picot-Allain, Ramasawmy, & Emmambux, 2022). In the food industry, pectin *per se*, is considered as a functional component, a gelling agent, and a stabilizer owing to its ability to form aqueous gels (Chen et al., 2015). Pectin is a highly industrially important hydrocolloid applied to various food products (Basak & Annapure, 2022). It is used in jams and jellies, fruit juice concentrates, fruit juice, desserts as well as fermented milk products (Chen et al., 2015). Along with its influence on the food industry, pectin is also used in a number of fields including medicine as a carrier for controlled drugs or bioactive release (Lara-Espinoza, Carvajal-Millán, Balandrán-Quintana, López-Franco, & Rascón-Chu, 2018).

The structure in addition to chemical composition of pectin are yet under discussion as a result of the high complexity of this molecule. The most recent consensus states that pectins are heterogeneous polysaccharides with three main structural domains: homogalacturonan, rhamnogalacturonan I and rhamnogalacturonan II (Liu, Willför, & Xu, 2015; Pasandide, Khodaiyan, Mousavi, & Hosseini, 2017). Xylogalacturonans, arabinogalactans and Arabians also fall into more structural classes of pectic polysaccharides (Lara-Espinoza et al., 2018; Voragen, Coenen, Verhoef, & Schols, 2009). It has been reported that pectin is composed of 50%-90% homogalacturonan (Pasandide et al., 2017).

In the course of its passage through the stomach and small intestine, pectin is resistant to endogenous digestive enzymes. However, it can be easily degraded by commensal bacteria in the gut with SCFA and other metabolite production (Larsen et al., 2019; Singh et al., 2019). Pectin can activate gut immunity, improve gut integrity in addition to mucosal proliferation and facilitate the adherence of probiotic *Lactobacillus* strains to epithelial cells (Larsen, Cahú, Saad, Blennow, & Jespersen, 2018).

According to several studies, dietary pectin may substantially alter the diversity and composition of the gut microbiota and the essential metabolites of acetate, propionate and butyrate (Beukema, Faas, & de Vos, 2020; Tan & Nie, 2020). Pectins may have an impact on the gastrointestinal immune barrier in a microbiota-dependent (indirect effects) and microbiota-independent (direct effects) manner. Direct effects include mucus layer-strengthening, stimulation of epithelial integrity or immune response modulation. Indirect effects involve microbial diversity stimulation, SCFAs production, adhesion of commensals to epithelial cells or the anti-adhesive effects of pathogens on epithelial cells (Beukema et al., 2020). Pectin and pectic oligosaccharides are fermented in the colon to promote the growth of various bacterial species such as *Bifidobacteria, Lactobacilli, Enterococcus, Eubacterium rectale, Faecalibacterium prausnitzii, Clostridium, Anaerostipes* as well as *Roseburia* spp. (Blanco-Pérez et al., 2021). It has been observed in cell culture studies that pectin modulates microbiota and induces varied microbial formation (Bang et al., 2018; Gómez, Gullón, Yáñez, Schols, & Alonso, 2016; T. Jiang et al., 2016; Mao et al., 2019). An increase in *Lachnospira, Dorea, Clostridium* and *Sutterella* bacteria was detected after pectin fermentation in an *in vitro* human fecal microbiome study (Bang et al., 2018). Pectins have displayed an increase in the amount of *Bifidobacteria, Lactobacilli, Faecalibacterium* and *Roseburia in vitro* (Gómez et al., 2016). In an *in vivo* study, citrus and rhamnogalacturonan-I (RG-I)-enriched pectin-increased *Ruminococcaceae* levels and decreased *Actinobacteria* amounts, whereas the depolymerized fraction of RG-I-enriched pectin-increased *Lactobacillus* levels and *Bifidobacterium* amounts. The same study revealed that both pectin fractions increased SCFA levels in the cecum (Mao et al., 2019). Apple-derived pectin leads to increased *Bacterioides* levels and *Firmicutes* bacteria levels, reduced metabolic endotoxemia and inflammation, in addition to weight gain prevention and adiposity in *in vivo* obese rat models (Jiang et al., 2016).

3.1.4. Inulin

Inulin, a linear fructan, is essentially composed of fructose units (β (2-1)) and generally contains one terminal glucose moiety (α (1-2)) per molecule (Abed et al., 2016; Kays & Nottingham, 2007; Kelly, 2009). The two non-digestible carbohydrates known as inulin-type fructans, oligofructose (OF) and inulin, are the most supported of all prebiotics. (Jackson, Wijeyesekera, Theis, van Harsselaar, & Rastall, 2022; Karimi, Azizi, Ghasemlou, & Vaziri, 2015). As a natural component, inulin is found in a range of herbs and vegetables. Sources particularly rich in inulin include root vegetables such as chicory and burdock root (belonging to the *Asteraceae* family), onion, garlic, leeks and *Jerusalem* artichoke (Tawfick, Xie, Zhao, Shao, & Farag, 2022). *Jerusalem* artichokes along with chicory root are the most widely used industrial sources of inulin for production (Ahmed & Rashid, 2019). With the unique property of acting as fat mimetics, long-chain inulin molecules are commonly used as fat substitutes to design low-fat foods and can be used in some dairy products including yogurt, cheese, frozen desserts, bakery products, creams, fillings, whipped cream, fiber supplements as well as processed meats (Ahmed & Rashid, 2019).

With its prebiotic properties, inulin can increase SCFA levels by fermentation through *Bifidobacterium* and colonic bacteria, leading to gut microbiota symbiosis. Thus, it is important in metabolic disorder prevention and/or treatment in numerous diseases including obesity, diabetes, cancer and kidney problems (Tawfick et al., 2022). When 10 grams of inulin was supplemented to obese female individuals with type 2 diabetes within a course of 8 weeks, it was observed that their fasting blood glucose levels, HbA1c and oxidative stress markers (malondialdehyde) declined, and that total antioxidant capacity in addition to superoxide dismutase levels increased, compared to that of the control group (10g maltodextrin)

(Pourghassem Gargari, Dehghan, Aliasgharzadeh, & Asghari Jafar-Abadi, 2013). In a double-blind, placebo-controlled study, 30 obese females were supplemented with inulin-type fructan prebiotics (inulin/oligofructose 50/50 mix; n=15) or placebo (maltodextrin; n=15) for 3 months. As a result of prebiotic supplementation, no change was detected in body weight, BMI, fasting insulin, HbA1C, fasting blood glucose, CRP, cholesterol (total, LDL, HDL) and triglyceride levels. Besides, the gut microbial composition in faeces with prebiotic supplemented group, *Bifidobacterium* and *Faecalibacterium prausnitzii* levels increased (both bacteria were negatively related with lipopolysaccharide levels), whereas *Bacteroides intestinalis, Bacteroides vulgatus* and *Propionibacterium* levels decreased (this effect was correlated with a slight decline in fat mass) (Dewulf et al., 2013). A study conducted on healthy persons revealed that natural chicory inulin consumption improved stool frequency in addition to consistency in elderly individuals with low stool frequency. However, it did not bring a significant change in gut microbiota composition (*Faecalibacterium, Bifidobacterium, Bacteroides, Alistipes* and *other certain bacterial taxa*) (Watson et al., 2019). In a systematic review of evidence from human studies indicated that after the inulin supplementation included increased relative abundance of *Anaerostipes, Faecalibacterium* in addition to *Lactobacillus* and decreased relative abundance of *Bacteroides* (Le Bastard et al., 2020).

3.1.5. Konjac glucomannan

Konjac glucomannan (KGM) is a polysaccharide, which is soluble in water and which is extracted from *Amorphophallus konjac*. It consists of glucose and mannose linked by β 1,4-glycosidic linkage (Ariestanti et al., 2019; Hayeeawaema, Wichienchot, & Khuituan, 2020; Ji, Xue, Feng, Li, & Xue, 2017). KGM is applied as a food additive due to its gelling enhancer, emulsifier, thickener and film-forming properties (Devaraj, Reddy, & Xu, 2019; Ji et al., 2017). It is a hydrocolloid dietary fiber extensively applied in medicinal products and as traditional food in konjac jelly, tofu, noodles as well as other pasta-like products (Devaraj et al., 2019; Ji et al., 2017). It is emphasized that KGM involves beneficial activities that are anti-diabetic, anti-obesity, laxative, prebiotic and anti-inflammatory (Devaraj et al., 2019). During the examination of the prebiotic potential of KGM hydrolysate *in vitro* in human stool samples, all populations of the *Bifidobacterium genus, Lactobacillus–Enterococcus* and the *Atopobium* groups increased significantly after both KGM and inulin fermentation. While the population of the *Bacteroides-Prevotella* group declined after KGM fermentation, the bacteria levels of this class increased after inulin fermentation and these differences were not found to be significant. As with inulin, KGM boosts beneficial gut microbiota. Also, it may produces a proper SCFA profile (Connolly, Lovegrove, & Tuohy, 2010). In a study conducted in mice with loperamide-induced constipation, the impact of konjac oligo-glucomannan (KOG), formed by the enzymatic hydrolysis of KGM, on gut motility and microbiota was studied. KOG substantially increased stool frequency and small intestinal transit in comparison to that of the healthy control class. However, it decreased total intestinal transit time. KOG brought an increase to the number of *Bifidobacterium* spp. and it decreased the number of *Clostridium* spp. and *Bacteroides* spp., significantly inhibiting the effects of loperamide on the gut microbiota (Hayeeawaema et al., 2020). A human study observed that KGM supplementation to subjects with constipation selectively triggered the growth of *Bifidobacteria* and *Lactobacilli*, which promoted effective bowel movement, while a decrease in *Clostridia* was detected (Chen, Cheng, Wu, Liu, & Liu, 2008). In contrast to this study, it was observed that high KGM dosage (8%) supplementation to C57BL/6J mice fed with a high-fat diet had no effect on *Bifidobacteria* and *Lactobacilli* levels. However, it significantly reduced parameters related to body fat accumulation, weight gain, inflammation in addition to a decline in liver damage (Song et al., 2021). Fermentation of KGM has been correlated with higher faecal acetate, propionate in addition to butyrate concentrations and decreased faecal pH (Chen et al., 2008).

3.2. Seed gums

3.2.1. Guar gum

Guar gum, one of the naturally occurring polymers of the *Leguminosae* family, is a galactomannan derived from the ground endosperm of *Cyamopsis tetragonolobus* or *Cyamopsis psoralioides* (Hamza, Qadeer, Alsaiari, & Alsayari, 2022). It is a powder with no odour and which is white-yellowish. It is applied as a raw material in the food industry. It consists mostly of a high molecular weight hydrophilic polysaccharide that is water- soluble, while it is typically insoluble in alcohol, ester, ketone, oil and hydrocarbon. It is applied for emulsification, stabilization, preservation, water retention and increasing water-soluble fiber content (Sharma et al., 2018; Theocharidou, Mourtzinos, & Ritzoulis, 2022). It is also used in dairy products (yogurt, cheese, ice cream), bakery products such as cakes and pasta, as well as sauces and beverages (to reduce energy) (Sharma et al., 2018). Guar gum is a dietary fiber that is soluble and it is not digested in the gastrointestinal tract. It also has a prebiotic effect due to its properties including the production of high SCFA levels (Ohashi et al., 2015; Ohashi et al., 2012).

Kapoor et al. (2017) concluded that partly hydrolysed guar gum supplementation in healthy subjects had a positive effect resembling laxatives in constipation prevention (Kapoor, Sugita, Fukuzawa, & Okubo, 2017). It is stated that guar gum has crucial effects on gut microbiota. In a double-blind, placebo-controlled analysis, the effect of partially hydrolysed guar gum on bowel movements (stool shape and frequency), gut microbiota and plasma bile acids along with quality of life were evaluated in 44 healthy volunteers prone to irritable bowel syndrome diarrhoea. Participants who received partially hydrolysed guar gum in a course of three months were found to have significantly improved stool structure compared to that of placebo groups. However, no effect was observed on stool frequency. Additionally, regarding to microbiota, it was observed that *Bifidobacterium*, *Ruminococcus* and *Megasphaera* levels significantly developed in the partially hydrolysed guar gum group, and the levels of *Bacteroides* along with *Phascolarctobacterium*, an unclassified type belonging to the *Lachnospiraceae* family, substantially decreased (Yasukawa et al., 2019). In another study, partially hydrolysed guar gum was given to ten healthy volunteers within a course of 2 weeks (6 g/day). Faecal SCFA (acetate, propionate and butyrate) levels showed no significant change. However, it was found that levels of faecal *Bifidobacterium*, *Clostridium coccoides* groups, the *Roseburia/Eubacterium rectale* group, the *Eubacterium hallii* group and the bacterium strain SS2/1 significantly increased through the intake of partially hydrolyzed guar gum, while there was no change in the that of the *Clostridium leptum* subgroup, the *Clostridium clusters* I and IX group, the *Bacteroides fragilis* group, the *Atopobium* cluster, *Prevotella* group and *Enterococcus,* the *Lactobacillus* group. It was concluded that PHGG might promote health by stimulating healthy bacteria in the human large intestine (Ohashi et al., 2015).

3.2.2. Fenugreek gum

Fenugreek is a legume plant of the Fabaceae class, widely cultivated as a semi-arid crop in North Africa, the Mediterranean, India and Canada (Salarbashi, Bazeli, & Fahmideh-Rad, 2019). The prevalent constituent of fenugreek seeds is galactomannan which is a polysaccharide composed of 1→4 β-D-mannosyl units structurally substituted by a single-α-linked galactose unit at the C-6 oxygen (Jiang, Zhu, Zhang, & Sun, 2007). Fenugreek is a hydrocolloid and its soluble fiber is fenugreek gum (Im & Maliakel, 2008; Wani & Kumar, 2018).

Fenugreek seeds are a functional and nutraceutical source, which are rich in gum, fiber, alkaloids, flavonoids, saponins and volatile components (Khorshidian, Yousefi Asli, Arab, Adeli Mirzaie, & Mortazavian, 2016). Due to its high fiber content, fenugreek can be applied as a food stabilizer, adhesive and emulsifying agent for the change of food-structure for several special purposes (Khorshidian et al., 2016). Fenugreek fiber, essentially, soluble fiber, can be added to dairy products, some functional beverages, yogurt and cereal bars. It is used to enrich flour in products including muffins, pizza, pita bread, cake mix, bread, bagels, tortilla or noodles in addition to fried and baked corn chips (Im & Maliakel, 2008; Wani & Kumar, 2018).

Fenugreek seeds have anti-inflammatory, cholesterol-lowering, hypoglycemic, anti-cancer, immunological activity, antinociceptive and gastroprotective impacts on human health (Khorshidian et al., 2016; Mandegary et al., 2012; Sharififar, Khazaeli, & Alli, 2009; Wani & Kumar, 2018). A study using an *in vitro* model that mimics in vivo conditions indicated that 71.4% of galactomannan extracted as prebiotic fiber from fenugreek seeds was used and fermented by *Bacillus coagulans* MTCC 5856, leading to a significant increase in SCFA production. It was also found that *Bacillus coagulans* MTCC 5856 obstructed *Escherichia coli* ATCC 25922 growth when co-cultured with galactomannan. This study indicated that galactomannan obtained from fenugreek seeds play an important role as prebiotics in modulating gut microbiota by functioning as a substrate for beneficial bacteria (Majeed et al., 2018). When 1.5 g/kg fenugreek seeds were fed to pigs for 28 days, it was observed that the cecum and colon pH levels decreased compared to that of the control group, and SCFA concentrations indicated no change except for the increase in n-butyric acid. When the effect on microbiota was examined, it was found that Lactobacillus and *Clostridium* cluster I concentrations were higher and *Escherichia, Hafnia* and *Shigella* concentrations were lower in the small intestine (Zentek et al., 2013). Another study revealed whether fenugreek uses gut bacteria to counteract the adverse impacts of diets high in fat. To this end, C57BL/6J mice were fed a control/low-fat or high-fat diet with or without fenugreek for 16 weeks. It was seen that in mice fed with 2% fenugreek, there was a statistically significant increase in α-diversity compared to that of mice fed with a control/low-fat or high-fat diet alone. Fenugreek was also found to rectify the dysbiotic effects of the high-fat diet on gut microbial populations (Bruce-Keller et al., 2020).

3.2.3. Cassia seed gum

Cassia obtusifolia L. is isolated from the purified endosperm of cassia tora seeds, also known as *Cassia obtusifolia*, of the Leguminosae family, and is commonly found in subtropical regions in the world (Feng, Yin, Nie, Wan, & Xie, 2018; Gałkowska, Pycia, Juszczak, & Pająk, 2014) Cassia seeds are an essential source of galactomannan which is extracted from the seed endosperm (Miao et al., 2021). Cassia seed gum displays a highwater retention capacity. It swells in water and forms high viscosity aqueous colloids after boiling. For this reason, Cassia seed gum is applied as a thickener. It has also been used as a stabilizer in the food industry and has an economic advantage (Gałkowska et al., 2014).

Cassia seed galactomannan oligosaccharides are stable during gastrointestinal digestion, and it is cited that they produce acetic acid and propionic acid due to fermentation, thereby reducing intestinal pH. The effect of indigestible galactomannan oligosaccharides obtained from Cassia seed gum on the microbiota composition and metabolites of human faecal inoculum was examined. An increase was observed in the potentially beneficial types including *Bifidobacterium, Lactobacillus, Bacteroides*, and *Veillonella*, whereas the growth of the potentially harmful types of *Fusobacterium, Lachnospiraceae* and *Sutterella* was obstructed (Miao et al., 2021). In a further study, it was observed that manno-oligosaccharides obtained from Cassia gum might be used as a kind of potential prebiotic, which effectively boosts the growth of three *Bifidobacterium* and six *Lactobacillus* strains with a three-fold increase in culture absorbance (Tong et al., 2020).

3.2.4. Basil seed gum

Ocimum basilicum Linn., also known as basil, is an endemic plant which grows in Iran (Naghibi, Mosaddegh, Motamed, & Ghorbani, 2022). It has been revealed that polysaccharides derived from basil seeds include two main fractions, which are glucomannan (43%) and (1→4)-linked xylan (24.29%) as well as a minor fraction, which is glucan (2.31%) (Hosseini-Parvar, Matia-Merino, Goh, Razavi, & Mortazavi, 2010). Recently, basil gum has become popular interest for its health advantages similar to dietary fiber and its superior functions as a thickener, emulsifier, gel formulators, fat replacer and stabilizer (Naji-Tabasi & Razavi, 2016). Basil seeds are used in beverages, desserts and beverages as a source of fiber and as laxative agents (Hosseini-Parvar et al., 2010; Khanongnuch & Wongputtisin, 2015). Consumption of these seeds lead to beneficial antimicrobial, antioxidant and anticancer activities (Calderón Bravo, Vera Céspedes, Zura-Bravo, & Muñoz, 2021).

The gum surrounding basil seeds is a source of prebiotic substance. One study investigated the prebiotic effect of the production of crude oligosaccharide from basil seed gum through enzymatic hydrolysis. The growth of *Pediococcus acidilactici* and *Enterococcus faecium* was triggered in the medium containing basil oligosaccharide compared with glucose as carbon. Additionally, total lactic acid bacteria increased in the stools of subjects who were supplemented with basil oligosaccharide, whereas a reduction was observed in *Salmonella* spp. and *Shigella* spp. (Khanongnuch & Wongputtisin, 2015).

3.2.5. Oat gum

Oat β-glucans (1 → 3) and (1 → 4) obtained from oat cell walls are unbranched (Jayachandran, Chen, Chung, & Xu, 2018). Consumption of sufficient numbers of oat products has been proven to lower the cholesterol of the host and thus, regulate the risk of cardiovascular disease (Grundy, Fardet, Tosh, Rich, & Wilde, 2018; Joyce, Kamil, Fleige, & Gahan, 2019). Owing to its gel-forming properties, oat β-glucan regulates bile acid and cholesterol metabolism of the host. It also eliminates intestinal cholesterol secretion (Joyce et al., 2019). Increased intestinal viscosity is one of the key mechanisms responsible for lower absorption of sugars and bile acid (Wolever et al., 2010; Zhang et al., 2016). These components have been proven to be beneficial for health and they can be used as functional ingredients in foods (Brennan & Cleary, 2005). Besides its nutritional benefits, oat β-glucan has extremely important physicochemical properties, including high water retention capacity, high viscosity, gelling and emulsification (Bai et al., 2021). The specified properties have increased the use of β-glucan in numerous fields of daily life, including the food industry to boost food texture or in the pharmaceutical industries as functional additives (Bai et al., 2021; Bai et al., 2019). Oat gum isolated from oat bran is extensively applied in the food industry due to its synergistic effect with suitable gum combinations. Appropriate gum combinations play an important role in the improvement of product quality, including nutritional properties, and in providing economic advantages (Zarzycki, Ciołkowska, Jabłońska-Ryś, & Gustaw, 2019).

As a source of β-glucan, oat, and oat products modulate gut microbiota in cell and animal models and in human studies (Bai et al., 2021; Connolly, Tzounis, Tuohy, & Lovegrove, 2016; Shen et al., 2010; Su, Miao, Wang, Wang, & Zhang, 2013). The fermentation of oat develops the population of *Bifidobacterium* (Kedia, Vázquez, Charalampopoulos, & Pandiella, 2009; Kristek et al., 2019), *Lactobacillus* (Kedia et al., 2009) and *Bacteroides* (Kristek et al., 2019), *Proteobacteria* (Kristek et al., 2019). Additionally, it causes a decrease in the population of *Clostridium* (Kedia et al., 2009), *Actinobacteria* and *Firmicutes* (Chappell, Thies, Martin, Flint, & Scott, 2015). Connolly et al. (2016) examined the effects of whole-grain oat granola on decreasing cholesterol levels in hypercholesterolemic individuals and detected a substantial decrease in total cholesterol levels in addition to low-density lipoprotein cholesterol (LDL) after the consumption of 45 g of whole-grain oat granola within a course of 6 weeks. In addition, a significant boost in the abundance of *Bifidobacteria* and *Lactobacilli* in the faecal microbiota of individuals following oat consumption compared with whole grain-free breakfast cereal was observed (Connolly et al., 2016). Similarly, a recent study showed that the consumption of oat bran containing 8.9 g of dietary fiber per day (30 g/day) reduced blood pressure and increased the relative abundance of faecal *Bifidobacterilerium* as well as *Apirillum* in the Chinese population (Xue et al., 2021). Contrary to this study, in another analysis conducted in China, no statistically substantial rise was found in *Bifidobacteria* and *Lactobacilli* levels after consuming 80-g oat (3g β-glucan) within a course of 45 days. In the same study, the amount of *Akkermansia muciniphila* and *Roseburia* as well as the relative amount of *Dialister*, *Butyrivibrio* and *Paraprevotella* were found to significantly increase, while unclassified *Sutterellaceae* levels decreased in fecal samples. Evaluated together, these findings show that oat consumption significantly reduces total cholesterol and LDL and mediates a prebiotic effect on gut microbiota (Xu et al.,2021). Therefore, it can be stated that oats may have advantageous effects on human health through SCFA production.

3.2.6. Psyllium

Psyllium is an important source of fiber found in the seed husks of the *Plantago ovata* (Belorio & Gómez, 2022). Psyllium is hydrocolloid due to its functional properties such as solubility and viscosity (Arabshahi & Sedaghati, 2022; Belorio & Gómez, 2022). Psyllium gum is obtained with a series of extractions of psyllium husk. It is stated that its consumption provides nutritional advantages including decreasing the glycemic index, the risk of cardiovascular related disease, cholesterol as well as constipation problems. It is used in various food products such as classic or gluten-free breads, pasta, pizza, cakes, cookies, dairy products, jellies, jam and mayonnaise. It has an anti-staling effect and is a fat and gluten replacer. It also provides nutritional enrichment and sensory enhancement in food products (Belorio & Gómez, 2022).

As a psyllium polysaccharide, it contains a combination of D-xylose, arabinose, galactose, rhamnose and D-galacturonic acid (Guan, Yu, & Feng, 2021; Guo, Cui, Wang, & Christopher Young, 2008). Psyllium is thought to have prebiotic potential, as some members of gut microbiota can use these oligosaccharides and their sugars as energy sources (Jalanka et al., 2019). In the randomized controlled double-blind study by Jalanka et al., psyllium supplementation was found to have a modest yet substantial impact on microbial formation by developing levels of *Veillonella* and by decreasing amounts of *Subdoligranulum* in the microbiota of healthy adults within a course of 7 days (Jalanka et al., 2019). Besides, in patients with constipation, it has affected acetate and propionate levels. It has also lead to more significant results on microbial formation by increasing *Lachnospira, Faecalibacterium, Phascolarctobacterium, Veillonella* and *Sutterella*, as well as reducing levels of uncultured *Coriobacteria* and *Christensenella* (Jalanka et al., 2019). Another study conducted on females with chronic constipation revealed that there was a boost in the amount of *Faecalibacterium* (butyrate-producing bacteria associated with fiber uptake), *Romboutsia, Streptococcus* and *Bifidobacterium* in the microbiota of the group treated with psyllium husk and a decrease in the abundance of *Lachnospiraceae, Megamonas, Megasphaer, Paraprevotella, Lactobacillus* and *Bacteroides* (Yang et al., 2021). Wistar rats fed with yogurt supplemented with partially hydrolyzed psyllium husk (PHPH) showed a significant decrease in triglyceride, total cholesterol and LDL cholesterol and a substantial rise in HDL cholesterol levels on day 60. Additionally, SCFA concentration and the amount of *Lactobacillus* were found to be greater in the stools of rats (Yadav et al., 2016).

3.2.7. Locust bean gum

Obtained from the carob tree (*Ceratonia siliqua* L.), locust bean gum (LBG) is found in the Mediterranean region. LBG can form an exceptionally viscous aqueous solution at considerably minimal concentrations. It can also stabilize emulsions and is applied for fat substitution in food products (Dakia, Blecker, Robert, Wathelet, & Paquot, 2008). Its D-mannose/D-galactose ratio is 4:1 and it has a galactomannan structure (Magengelele et al., 2021).

Similar to guar gum, locust bean gum remains the prevalent galactomannan used in the food industry owing to the lack of accessibility and high prices of tara and fenugreek gums (Seo, 2022). Carob gum is used in milk and dairy products, ketchup, fruit juice, pudding powder and some desserts (Saha & Bhattacharya, 2010). It can also be used in anti- reflux formulas (formulas with added thickener) for infants fed with formula due to persistent regurgitation, low weight gain or marked restlessness. Rice starch, corn starch or carob gum are used as thickeners in these formulas (Salvatore et al., 2018). One study investigated the effects of three different-thickening ingredients including carob gum, corn hydroxypropyl distarch phosphate and pregelatinized rice starch, on in vitro intestinal fermentability and infant microbiota. When carob bean gum was used, propionate and total SCFA molar concentrations were found to be higher than those in the other two groups. Regarding the bacteria population, the carob gam promoted a more diverse microbiota, which enhanced the growth of *Atopobium* and *Bacteroidetes*, while corn hydroxypropyl distarch phosphate and pregelatinized rice starch induced higher *Lactobacillus* and *Bifidobacteria* levels at the beginning of fermentation (González-Bermúdez, López-Nicolás, Peso-Echarri, Frontela-Saseta, & Martínez-Graciá, 2018). Among β-mannooligosaccharide combinations gathered from the hydrolysis of locust bean gum, oligosaccharides with polymerization degrees 2 and 3 boosted the development of three of seven *Lactobacillus* species under *in vitro* conditions, while those with polymerization degree 5 reduced the growth of all *Lactobacillus* spp. Additionally, these three degrees of polymerization were found to obstruct the development of *Escherichia coli*, *Listeria monocytogenes* and *Salmonella typhi* (Srivastava, Panwar, Prashanth, & Kapoor, 2017). C57BL/6J mice fed with a diet high in fat and supplemented with locust bean gum were found to have significantly increased levels of *Ruminococcaceae* UCG-013 genus, and the growth of *Desulfovibrio* was completely inhibited (Song et al., 2021).

3.2.8. Resistant starch

Starch is the most widely used thickening hydrocolloid (Saha & Bhattacharya, 2010). Some physicochemical properties, such as gel formation, increasing viscosity, water binding capacity and sizing make resistant starch (RS) one of the raw materials sought in the food industry (Demirekin & Hülya, 2016). It is relatively cheap and plentiful and does not add any significant flavour when applied at a minimal concentration of 2 to 5%. In addition, as a typical constituent of numerous foods, starch has the advantage of not imparting any different flavours, which may be the case in various gums. It is a hydrocolloid, which provides the basic texture in soups and sauces (Gibiński et al., 2006; Dipjyoti Saha & Suvendu Bhattacharya, 2010).

Starch accounts for more than 25% of the energy in the typical human diet (DeMartino & Cockburn, 2020). However, some types of starch, called resistant starches, are complex carbohydrates. RS can be categorized into four different varieties: physically inaccessible (ERS1), natural granular starch (ERS2), retrograde amylose (ERS3) and chemically modified starch (ERS4) (Maier et al., 2017; Yang et al., 2017). RS, which survives while passing through the stomach and small intestine without being digested, reaches the colon and shows prebiotic properties. Thus, it is fermented there by members of the gut microbiota, produces SCFAs including propionate, acetate as well as butyrate, and increases the activity of beneficial microorganisms (DeMartino & Cockburn, 2020; Dobranowski & Stintzi, 2021). It was revealed that the ERS1 type oat-defiant boosts the levels of genus *Clostridium* as well as *Butyricicoccus* and reduces *Bacteroides, Lactobacillus, Oscillospira* and *Ruminococcus* levels (Zhu et al., 2020). Ze et al. found that *Ruminococcus bromii* exhibited high degrading activity against ERS2 and RS3-resistant starches compared with other amylolytic human intestinal bacteria such as *Bacteroides thetaiotaomicron*, *Eubacterium rectale* and *Bifidobacterium ergenis* (Ze, Duncan, Louis, & Flint, 2012). Ordiz et al. investigated the effect of 8.5g of daily ERS2 supplementation within a course of 4 weeks on microbiota and SCFA of 18 stunted children aged 3-5 years from Malawi. It was found that while *Actinobacteria* increased at the phylum level after consumption, *Firmicutes* levels declined and *Bacteroides* amounts did not change. Among the frequent types, *Lactobacillus* levels increased while *Roseburia, Blautia* and *Lachnospiraceae incertae sedis* amounts declined. Among the SCFAs, acetate concentration decreased while the propionate concentration increased (Ordiz et al., 2015). A high RS diet has led to a rise in the ratio of *Firmicutes* to *Bacteroidetes* and the relative amount of certain constituents of *Firmicutes* (Maier et al., 2017). As a dietary fiber, RS has an important place in daily life and has beneficial effects on human health (anti-obesity, anti-inflammatory, reducing blood glucose, etc.) through gut microbiota (Wen, Li, Hu, Tan, & Nie, 2022).

3.3. Seaweeds

Red macroalgae which are edible (i.e., *Chondrus crispus*, *Palmaria palmata*, *Porphyra* spp. and *Mastocarpus stellatus*) are harvested industrially on the Pacific as well as the Atlantic coasts. Additionally, specific chosen red seaweed species, e.g., *Chondrus cripus* are cultivated on land. Red seaweeds have an abundance of phycocolloids (this can be carrageenans and agar) and phycobiliproteins. It is a beneficial origin of dietary fiber, mineral, vitamin, phorotannin, carotenoid, amino acid and several health-promoting compounds. It is also a raw material source for the nutraceutical as well as pharmaceutical corporations (Holdt & Kraan, 2011).

Constituents of seaweed, which can apply advantageous impacts on the gut through regulation of the amount and range of bacterial populations in gut microbiota comprise polysaccharides, polyphenols and peptides. The main brown, red and green seaweed polysaccharides are fucoidans, laminarin, alginate, carrageenan, porphyran and ulvans, while the main polyphenols are bromophenols and fluoro tannins (Shannon, Conlon, & Hayes, 2021).

The positive effects of seaweeds on gut microbiota are due to their prebiotic properties. Susabinori (*Porphyra yezoensis*), a red algea polysaccharides are reported as an ideal prebiotic owing to their selection by beneficial bacteria (especially *Bifidobacteria*) rather than pathogenic strains, their indigestibility (resistance to digestive enzymes) and their fermentability as a substrate for gut microbiota (Muraoka et al., 2008). It is thought in particular that some components in the seaweed structure are effective in demonstrating these effects. Some *in vitro* and *in vivo* studies revealed that, several polysaccharides found in seaweed, which cannot be digested in the upper gastrointestinal tract, have bioactive effects including promoting intestinal microbial and immune modulation by acting as glycemic control agents as well as prebiotics. Also, it was found that an increase in especially *Prevotella stercorea, Mitsuokella* spp. and *Bacteroides ovatus* (Chen et al., 2018; Hui et al., 2021; Zaharudin et al., 2021). It was concluded that edible seaweeds (*Undaria pinnatifida* and *Porphyra ternera*) carry prebiotic properties, which alter the metabolic movement and composition of good microbiota in rats (Gudiel-Urbano & Goñi, 2002). The first possible mechanism of action of seaweeds showing prebiotic effects is that they are resistant to digestive enzymes. The second is that they can be selected by beneficial bacteria and fermented. Third, they increase SCFAs. An *in vitro* study concluded that glycerol galactoside of the red algae *Pyropia yezoensis* is defiant to the effects of pancreatic salivary as well as digestive enzymes (Muraoka et al., 2008). A few algal polysaccharides are fermented by certain gut microbes subsets. For instance, neo agaro-oligosaccharides obtained from agarose are fermented through beneficial bacteria (*lactobacilli and Bifidobacteria*), not by pathogenic strains (Hu et al., 2006). A study conducted on laying hens showed that when red seaweed was added to the feed of hens, SCFAs increased in their intestines and the seaweed had a beneficial effect in terms of intestinal health (Kulshreshtha et al., 2014).

Seaweed polyphenols serve as alternate metabolites found in terrestrial plants everywhere (Sun, Warren, & Gidley, 2019). Due to their structural complexity, only 5%-10% polyphenols are absorbed by the gastrointestinal system. Large-polyphenol commixtures reaching the large intestine have the potential to be converted into useful bioactive metabolites through microbial activity, while they can also inhibit pathogenic species (Cardona, Andrés-Lacueva, Tulipani, Tinahones, & Queipo-Ortuño, 2013; Kumar Singh et al., 2019; Tomás-Barberán, Selma, & Espín, 2016). An *in vitro* study on phlorotannins showed a rise in the population of some beneficial bacteria including *Bifidobacterium, Lactobacillus,* and *Clostridium coccoides* after 24 h of fermentation (Charoensiddhi, Conlon, Vuaran, Franco, & Zhang, 2017).

Additionally, it is possible to apply seaweed as sustainable protein sources for peptide-based drug and functional food production for preventing diseases including cardiovascular diseases, diabetes and hypertension (Admassu, Gasmalla, Yang, & Zhao, 2018). Proteins and peptides derived from seaweed can be used as food substrates by some colonic bacterial families, including *Enterobacteriacea, Burkholderiacea, Desulfovibrionaceae, Peptostreptococcus* and *Clostridium* (Amaretti et al., 2019; Neis, Dejong, & Rensen, 2015). It is also stated that these seaweed-derived peptides are metabolized into amino acids as well as beneficial SCFA, and they can promote the proliferation along with the development of intestinal epithelial cells and provide potential benefits to the intestines (Shannon et al., 2021). In a human study, alginates were shown to be effective as a prebiotic in increasing the number of *Faecalibacterium prausnitzii,* a commensal gut bacteria thought to protect against inflammation (Murakami et al., 2021). In a human fecal cultures, the alginate and laminaran degrading bacteria such as *Bacteroide*s *xylanisolvens, Bacteroide*s *uniformis*, and *Erysipelatoclostridium ramosum*-like bacterias were identified as potential responsive human gut indigenous bacteria (RIB). In addition, alginate RIB *(Faecalibacterium prausnitz*i) and laminaran RIB (*Roseburia faecis* and

Roseburia inulinivorans-like bacterias) were also detected; however, there were individual differences in the numbers of these microorganisms (Lee et al., 2022).

As a result, seaweeds have beneficial effects on intestinal health by showing prebiotic properties, and this effect is related to their resistance to digestive enzymes and their ability to increase the number of pathogenic bacteria through being selected by beneficial bacteria and to increase the amount of SCFA. Additionally, studies on the application of seaweed as a sustainable source of protein have yielded important results. However, there is a need for more comprehensive studies in which the mechanisms can be clearly explained.

3.4. Microbial exudates

As an anionic, multifunctional gelling agent gellan is produced by the genus Sphingomonas and carries linear form based on a tetrasaccharide repeat unit consisting of two D glucose, one-L rhamnose and one D-glucuronic acid. It is esterified with acyl substituents naturally. Gellan has received acknowledgement for application in the food and medical industries in the USA and the EU (Fialho et al., 2008). It was found that the use of gellan was associated with greater water retention and the emergence of the cecum content as a hard gel in the faeces. The study in mice compared different hydrocolloids and reported that the common intake of food and weight gain of the body were identical in all classes. Additionally, no discrepancies were detected in the SCFA profile of gellan in comparison to the control group, which showed identical fermentation levels (Lindström, Holst, Hellstrand, Öste, & Andersson, 2012). However, it was also noted that the high viscosity of intestinal content may damage the digestion of nutrients and other commixtures (Kerckhoffs, Brouns, Hornstra, & Mensink, 2002). For example, diets comprising oats induce the growth of the cecum tissue and lead to organ enlargement in mice and rats (Immerstrand et al., 2010).

Produced by *Xanthomonas campestris*, xanthan was accepted as a food preservative without any quantity limitation. It displays pseudoplastic behaviour. It is also widely applied as a stabilizer in sauces (Palaniraj & Jayaraman, 2011). The structure of xanthan consists of a linear backbone with β-(1,4) glycosidic bonds similar to cellulose. The branches are composed of mannose and glucuronic acid. In an animal study, xanthan fermentation was found to produce the largest proportion and level of acetate in the intestine (Lindström et al., 2012).

Dextran is an α-(1,6) linked glucan branched mostly in the α-(1,3) position which is formed by several bacteria. However, *Leuconostoc mesenteroides* is the most commonly used one for commercial production. Dextran is applied to substitute blood plasma and is available in numerous food systems through on-site production (Naessens, Cerdobbel, Soetaert, & Vandamme, 2005). In an animal study, dextran significantly increased the total SCFA pool, such as propionic and butyric acid levels (Lindström et al., 2012). It is particularly important as significant amounts of SCFA as well as butyric acid may play a muco-protective role in the gut (Willemsen, Koetsier, van Deventer, & van Tol, 2003).

Basidiomycete Sclerotium rolfsii produces scleroglucan, which comprises a glucopyranose backbone with a β-(1,3) link and glucopyranosyl branches in a single β-(1,6)-link in each third subunit. Scleroglucan has not been acknowledged for application in the food industries in the EU and the USA, and it is commonly applied in Japanese food products (Schmid, Meyer, & Sieber, 2011). Thus, so far, no studies were carried out on the physiological effects of scleroglucan in literature. Only one analysis in mice found that scleroglucan at a concentration of 4.0% showed a clear effect on the gut of mice since a conclusive bulking effect was observed with an increased level of total SCFA in the cecum, along with acetic and butyric acid (Lindström et al., 2012). There is a limited evidence regarding the microbial-based food hydrocolloid effects on intestinal health. The effects of increased SCFA and increased water retention in faces have been discussed. However, it can be noted that there are very limited effects. For this reason, it is recommended to conduct more comprehensive studies, especially in humans.

3.5. Modified starch

Starch is naturally an abundant and prevalent polysaccharide. It is extensively applied in the food industry for gelling, stabilizing, thickening and replacing expensive components, potentially without changing a considerable amount of taste and smell. Yet, the susceptivity of native starch to retrogradation, mainly due to its high content in amylose, is a limitation to its industrial use. It also has several constraints of structural stability under extreme temperatures, pH and shear conditions (Manzoor et al., 2020).

Modified starch is a food ingredient obtained by processing starch or starch granules, and it causes partial degradation of starch (Samuel, 2016). Starch types are important dietary energy sources, for their interactions with the intestinal microbiome throughout the digestive system. To a large extent, these interactions improve human health. Starches, especially RS, other undigested carbohydrates and endogenous secretions, which escape small intestinal digestion, are inebriated in the large intestine by the host microbiome (Cione et al., 2021) and the resulting SCFAs contribute significantly to the normal physiological functions of the internal organs and health. Thus, certain kinds of RS, such as those used in the food industry, which are chemically modified, can be used to manipulate gut bacteria and food products (including SCFAs) to optimize health (Cione et al., 2021; Tan, Beltranena, & Zijlstra, 2021). Moreover, modified starch is more effective in showing prebiotic properties compared to other starch types. It can help transport probiotic organisms in the upper gut, thereby promoting the immune response and suppressing potential pathogen microorganisms (Bird, Brown, & Topping, 2000).

Modified starch displays minimal gastrointestinal side effects such as bloating and nominally alters the physicochemical as well as the organoleptic properties of the final food product. (Haub, Hubach, Al-Tamimi, Ornelas, & Seib, 2010; Martínez, Kim, Duffy, Schlegel, & Walter, 2010). These properties of modified starch make it significantly versatile and therefore an optimal fiber to be included in the routine diet for long-term metabolic syndrome management (Maziarz et al., 2013). It also improves lipid profiles and body composition owing to its potential to increase colonic SCFA production (Byrne, Chambers, Morrison, & Frost, 2015; Nichenametla et al., 2014). Studies on rats have shown that starches which are esterified with certain SCFAs by a reception with propionic, acetic or butyric anhydride ensure resistance to digestion in the small intestine and these SCFAs affect the microbiota in the large intestine (Annison, Illman, & Topping, 2003; Clarke, Bird, Topping, & Cobiac, 2007). In an animal study concluded that acetylation and cross-linking acts as a prebiotic by increasing the content of SCFAs in cecum digestion (Le Thanh-Blicharz et al., 2014). It has been reported that there is a need for well-designed studies, which can structurally combine the effect of starch as an operative and adaptable food component on the gut microbial community of the host, metabolic functions and bacterial metabolites in individuals with metabolic syndrome (Khaturia, Gautam, & Sharma, 2019).

ERS4 has been classified as a modified starch among RS and it is non-digestible. For this reason, it has been considered that the health advantages of ERS4 are primarily due to its effects on the gut microbial community formation, which in turn may be correlated with altered bacterial fermentation and SCFA production, which contributes to optimal colon function (Topping & Clifton, 2001). It was reported the effects of an ERS4-enriched diet on gut microbiota composition along with SCFA concentration in twenty human subjects with metabolic syndrome symptoms. In the study, an increase was observed in *Bacteroides, Parabacteroides, Oscillospira, Blautia, Ruminococcus, Eubacterium* and *Christensenella levels* and in the rate of valeric, propionic, butyric, isovaleric and hexanoic acids among the SCFAs, while a decrease was observed in isobutyric acid (Upadhyaya et al., 2016).

In summary, it has been stated that modified starch is used quite frequently in the food industry and it is non-digestible, has an impact on intestinal microbial community formation and increases the number of SCFAs, showing prebiotic properties.

3.6. Cellulose derivatives

Cellulosic materials are "generally recognized as safe (GRAS)" substances and thereby, are considered to be dietary fiber or useful additives for application of food (Mu et al., 2019). Cellulose and its varieties are accepted as ideal candidates to replace oil, as they are substitute products that can copy the food properties imparted by fats. They can alter properties of food by increasing viscosity and texture improvement (He et al., 2021).

Cellulose is produced from natural biological sources, roughly 50 billion tons per year (Hindi, 2017). Cellulose has been widely used in many areas recently due to its properties such as biocompatibility, renewability, having no toxicity and environmental friendliness. Various structures such as nano-crystalline cellulose (NCC), microcrystalline cellulose (MCC) and nano-fibrillated cellulose (NFC) are obtained from different processes (He et al., 2021).

NCC has displayed a higher number of beneficial effects on SCFA production than MCC and standard cellulose due to its exceptional swelling capacity and large surface area (Lu, Gui, Guo, Wang, & Liu, 2015;bLu, Gui, Zheng, & Liu, 2013). It has been observed that a NFC diet reduces fat absorption (Chen, Lin, Nagy, Kong, & Guo, 2020). Cellulose with a high surface load interacts with digestive system content. This increases the residual time and provides more space for NCC particles to collaborate with gut microbiota (Koshani & Madadlou, 2018). It is also reported that fermentable cellulose in diet can alter the bacterial population in broilers (Zeitz et al., 2019). Soluble cellulose may have a different effect on gut microbiota. In an animal study, it was showed that MCC can induce inflammatory diseases and potential risks promoting obesity/metabolic syndrome. For this reason, it has been stated that attention is required on the negative effects of cellulose esters (Chassaing et al., 2015)

Properties of colloidal cellulose, such as crystalline structure, high aspect ratio, surface load and wettability of cellulose contribute to the balance of colloidal structures and enhance nutritional properties of cellulose by enabling interactions with the digestive system (He et al., 2021). Cellulose can function as a dietary fiber in the gastrointestinal system (Nsor-Atindana et al., 2017). In this way, the control of blood glucose levels can induce the production of SCFAs in the gut, potentially having benefits on the microbiota (He et al., 2021). Besides, an animal study involving high- and low-cellulose diets showed that dietary cellulose plays a beneficial role in maintaining intestinal homeostasis (Kim et al., 2020).

All non-digestible yet fermentable carbohydrates increase fermentative activity in the body, especially in the proximal colon, and boosts the formation of acid. This lowers luminal pH with substantial outcomes for compositing the microbiota and the stability of microbial metabolites (Flint, Scott, Duncan, Louis, & Forano, 2012). Cellulose is fermented in the column and SCFAs such as propionate, acetate and butyrate are formed (Yang, Cao, & Zhang, 2010; Zhou et al., 2014). Both natural and fermented cellulose have proven to be resistant to bacterial degradation followed by remaining in the gut for a specific duration (Jonathan et al., 2012; Peng et al., 2018). It was reported the impact of dietary lignocellulose supplementation on the gut microbiome along with inflammation-related genes in broilers and found that fermentable lignocellulose in diets can change bacterial population by decreasing the amount of *Lactobacillaceae, Firmicutes,* and *Ruminococcaceae* levels and by raising the amounts of *Erysipelotrichaceae, Peptostreptococcaceae* and *Enterobacteriaceae* (Zeitz et al., 2019).

Cellulose is known to be important for gut health, as a dietary fiber and for its ability to be fermented. Yet, further investigations are required due to the possible negative impacts of some types of cellulose on gut microbiota and human health.

3.7. Animal exudates – gelatine, chitin, and chitosan

Gelatine is a protein-based food additive obtained owing to the hydrolysis of collagen, which is a basic and structural protein of animal tissues. Gelatine, which is obtained through several processes involving the degradation of tertiary, secondary and partially primary protein structures of collagen, is a water-soluble substance and is an important hydrocolloid with high molecular weight, obtained from the white combining tissues, skin and animal bones (Erge & Zorba, 2018).

Its functional properties in the food industry are examined in two groups. The first group is the gelling ability and the second is the surface behavior (Gómez-Guillén, Giménez, López-Caballero, & Montero, 2011). The most important differences which distinguish gelatine from other hydrocolloids is its ability to melt reversibly at temperatures below human body temperature, its natural protein structure of animal origin and the fact that it is an additive with GRAS status (Erge & Zorba, 2018).

Chitin, a naturally existing polysaccharide, is considered as a highly ample biopolymers in nature, and its derivatives such as chitosan, are from non-vegetarian sources including insects, crustacean exoskeletons and fungi (Lopez-Santamarina et al., 2020). Chitosan oligosaccharides (COS) are prepared from chitosan, an N-deacetylated derivative of chitin (Thadathil & Velappan, 2014). COS's diverse biological functions are aided by its solubility in water and low toxicity (Muanprasat & Chatsudthipong, 2017). COS has various properties such as antimicrobial (B. K. Choi et al., 2001), anti-inflammatory (Yousef, Pichyangkura, Soodvilai, Chatsudthipong, & Muanprasat, 2012) anti-diabetic activities (H.-W. Lee, Park, Choi, Yi, & Shin, 2003). This ensures the widespread use of COS (C. Zhang, Jiao, Wang, & Du, 2018). Although *Lactobacillus* spp. and *Bifidobacterium bifudium* grow more rapidly when exposed to COS in pure cultures, this effect has not been shown in human stool samples. (Lee, Park, Jung, & Shin, 2002; Vernazza, Gibson, &

Rastall, 2005). In a human trial, chitin-glucan supplementation increased bacterial metabolites in stools (Rodriguez et al., 2020). Different COS sources and experimental studies may yield different results (Lee et al., 2002; Mateos-Aparicio, Mengíbar, & Heras, 2016; Zou et al., 2016). However, the mechanism and causality of this association, particularly the direct effect of COS on gut microbiota, have not been thoroughly addressed. It has been hypothesized that there may be a relationship between COS, gut microbiota and the health of the gut of the host in an animal study (Zhang et al., 2018).

Owing to its prebiotic potential (Selenius, Korpela, Salminen, & Gomez Gallego, 2018), chitin improves gastrointestinal health. In addition to its effects on human gut microbiota, chitin and its sources are considered as functional dietary fibers that can lower blood levels of LDL-cholesterol when consumed in foods (Caparros Megido et al., 2014; Choi et al., 2012). With mice fed on a diet high in saturated fat, chitin consumption improves increase insulin secretion, glucose intolerance, alleviate dyslipidemia and protects gut integrity as well as gut microbiota (Zheng et al., 2018). An in vitro study it has also been stated that chitin or its derivative has antimicrobial properties as well as antiviral, anticancer and antifungal activity in addition to a bacteriostatic impact on Gram-negative bacteria, which are *Vibrio cholerae*, *Escherichia coli* and *Shigella dysenteriae* (Piccolo et al., 2017).

Chitin and its sources have been considered as obstructers of bacterial development in pathogenic microorganisms including Enteropathogenic *Escherichia coli* and *Salmonella typhimurium* (Benhabiles et al., 2012; Rinninella et al., 2019). In addition to inhibiting pathogen growth, it has been reported that the intake of chitin does not exert the same effect on beneficial bacteria such as *Lactobacillus* and *Bifidobacterium* (Imathiu, 2020). Chitin consumption triggers the development of good bacteria in the gut microbiota. Stull et al., (2018) noted that the inhabitation of cricket chitin increased the proliferation of *Bifidobacterium animalis* 5.7-fold in adult human microbiota (Stull et al., 2018). Similarly, another in vitro study found that the inhibitory activity against Gram-negative bacteria was greater than that of anti-Gram-positive bacteria (Selenius et al., 2018).

The insect application or supplementation impacts have no continual effect on the gut microbiota of laying hens or broilers (Biasato et al., 2020; Borrelli et al., 2017; Józefiak et al., 2020; Marono et al., 2017), species of fish including rainbow trout (O. mykiss) (Rimoldi, Gini, Iannini, Gasco, & Terova, 2019; Terova et al., 2019), zebrafish (Danio rerio)(Osimani et al., 2019), Siberian sturgeon (Acipenser baerii)(Józefiak et al., 2020) and mice (Jia et al., 2019). In most cases, although some beneficial effects were found, in all cases, some damaging effects were also found in the combination of the microbiota of the gut. The fact that both insects employed and the pulp made from them had a higher protein content than chitin has been used to explain these contradicting results. High protein diets are dysbiotic, which is frequently the case with Western diets. (Roca-Saavedra et al., 2018).

In comparison to entire insects or insect pulp, chitin derivatives have better metabolic and gut microbiota effects. It was revealed beneficial effects of chitosan-containing foods on the gut microbiota as being limited to foods lacking in protein content (Rinninella et al., 2019) This explains the exceptional efficacy of chitin sources as a result of the high protein content in meals which are both insects and insect-derived (Imathiu, 2020), the dysbiotic effect of protein-rich diets (Alam et al., 2016; Liu et al., 2015; Zmora, Suez, & Elinav, 2019).

Chitosan, the simplest chitin derivative, was associated with an improved serum lipid profile as it has metabolic effects such as decreasing dietary consumption and body weight in investigations on pigs (Egan Á, Sweeney, Hayes, & O'Doherty, 2015); metagenomic data support crucial metabolic pathways including vitamin production. (Yu et al., 2017); and there is a decrease in triglyceride, cholesterol, and aspartate aminotransferase on hamsters(Tong et al., 2020). Concerning the direct impact of chitosan on the gut microbiota, it was linked to a decrease in Firmicutes on pigs (Egan Á et al., 2015; Yu et al., 2017) and a rise in the number of Bacteroidetes on pigs (Yu et al., 2017). A greater scale of Firmicutes to Bacteroidetes has been correlated with a higher obesity risk in humans (Magne et al., 2020).

It might be mentioned that chitin derivatives, such as chitosan, only exhibit their potential prebiotic properties when ingested with diets that are low in protein. Chitin derivatives yield better in altering the gut microbiota, triggering the proliferation of good bacteria while lowering that of several pathogenic bacteria.

Additionally, the anti-inflammatory properties of chitin derivatives, the stimulation of the immune system and diabetes obstruction/management along with obesity are all favourable consequences (Lopez-Santamarina et al., 2020). Chitosan oligosaccharides (COS) have had positive effects on the microbiota of the gut in a study on mice (C. Zhang et al., 2018).

Among the prominent features of animal-derived hydrocolloids in terms of intestinal health is the increase in the amounts of good bacteria alongside the decrease in the amounts of hazardous bacteria. To fully comprehend the impacts on the microbiota, especially the bacterial population, more research on humans is necessary.

4. Conclusions

Food hydrocolloids are versatile natural food ingredients that may be originally present in food matrices or added as functional food ingredients and/or food additives. In recent years, studies have been conducted on its effects on human health and well-being. Novel literature suggests that some food hydrocolloids can significantly alter the range and structure of the gut microbiota and primary bioactive metabolites, including SCFAs. In this way, it can directly/indirectly affect host health, so it would be fair to call this interaction the food hydrocolloid-gut health axis. Food hydrocolloids modulate the health of the host through a series of systems associated with their derivatives, chemical structures and derivative forms, fermentability, as well as their physiological activities in the gut, by exerting a prebiotic effect. However, it is important to explain how very low doses of hydrocolloids added to processed foods can affect health. While investigating the possible health and safety effects of using hydrocolloids as food additives, it may be useful to investigate the benefits and side effects of using different doses, especially on the gut. In addition, randomized controlled trials of the gut-modulating effects of animal and microbial-derived hydrocolloids are scarce so far. The available literature appears to be mostly based on cell culture and animal models. Therefore, randomized controlled trials warrant to elucidate the possible metabolic systems of all food hydrocolloids in different forms that contribute to health through gut modulation.

Conflicts of Interest

None. The authors declare that they have no known competing financial interests or personal relationships, which may have appeared to influence the work covered in this paper.

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Figures

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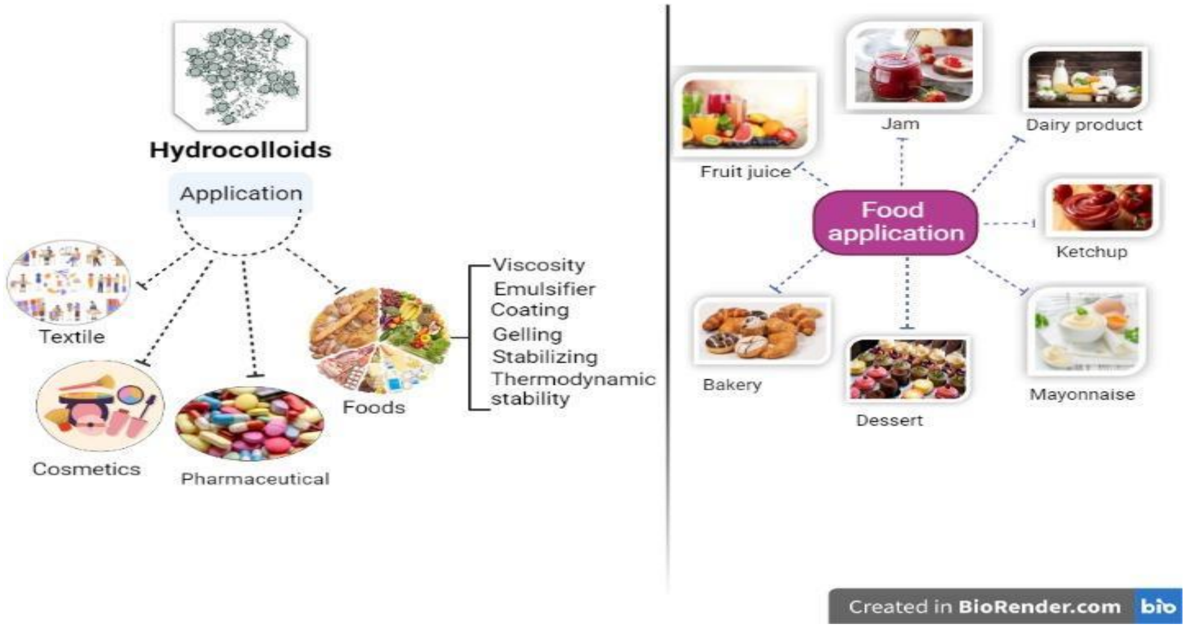

1682 **Figure 1.** Hydrocolloids and their food applications

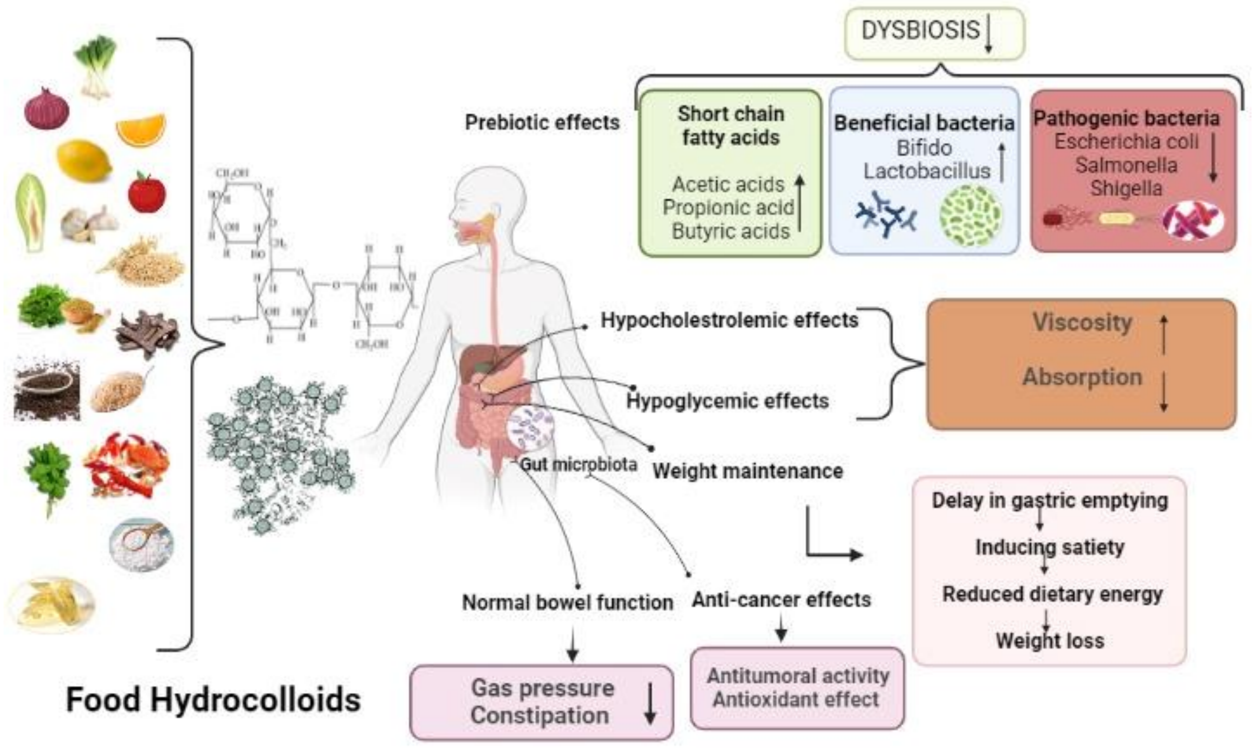

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Figure 2. Food hydrocolloids and their potential health effects through gut modulation

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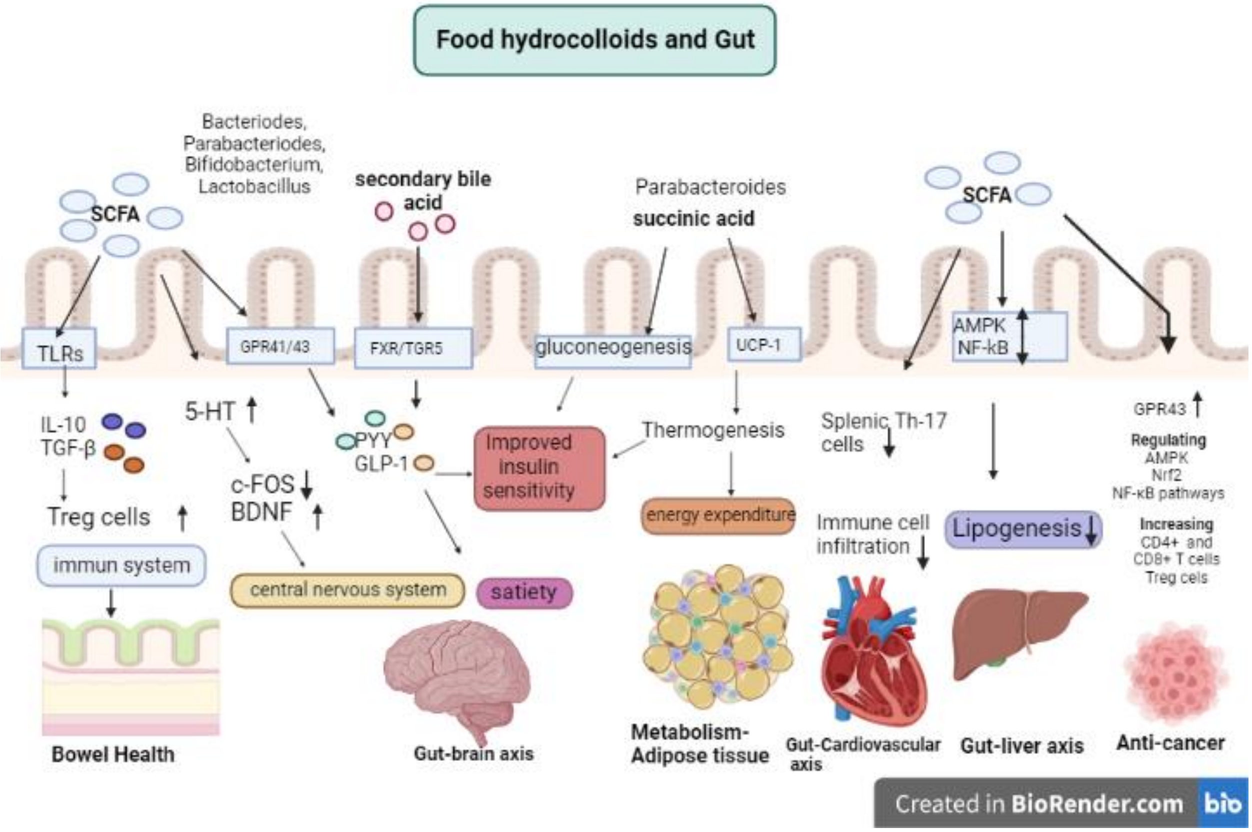
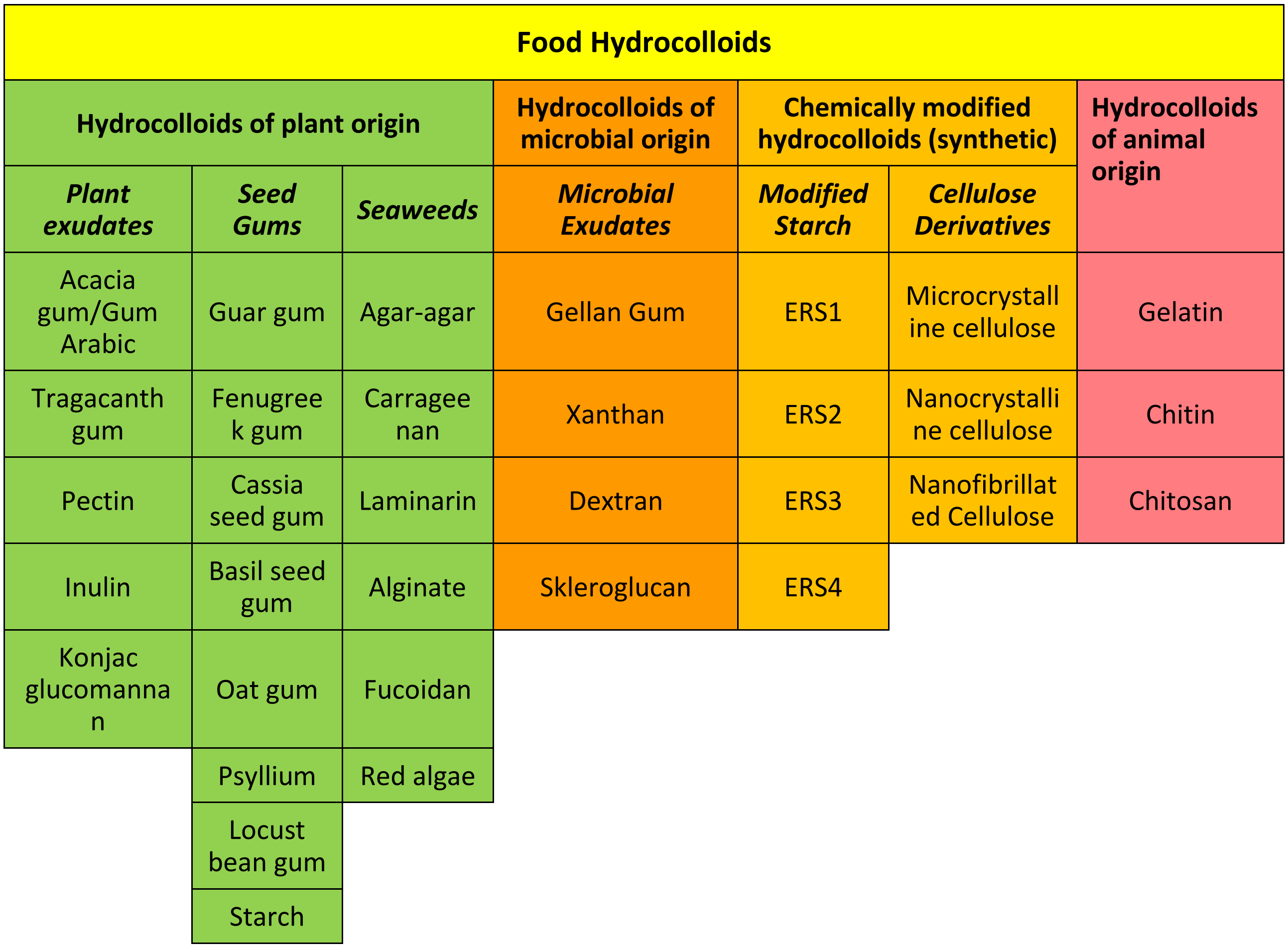


Figure 3. Molecular Mechanism of Hydrocolloids on Gut.

IL: interleukin, TGF-β: Transforming growth factor-beta; Treg: Regulatory T; 5-HT: 5-hydroxytryptophan; BDNF: brain-derived neurotrophic factors; GPR: G-protein−coupled receptors; FXR: farnesoid X receptor; TGR: the G protein-coupled bile acid receptor 1; NF-κB, nuclear factor kappa B; PYY: peptide YY; GLP-1: glucagon-like peptide 1; UCP: uncoupling protein; Th-17: T-helper 17; AMPK: adenosinemonophosphate-activated protein kinase; SCFA: *Short-chain fatty acids*; Nrf2: nuclear factor erythroid-2-related factor-2; CD: cluster of differentiation



Food Hydrocolloids						
Hydrocolloids of plant origin			**Hydrocolloids of microbial origin**	**Chemically modified hydrocolloids (synthetic)**		**Hydrocolloids of animal origin**
Plant exudates	***Seed Gums***	***Seaweeds***	***Microbial Exudates***	***Modified Starch***	***Cellulose Derivatives***	
Acacia gum/Gum Arabic	Guar gum	Agar-agar	Gellan Gum	ERS1	Microcrystalline cellulose	Gelatin
Tragacanth gum	Fenugreek gum	Carrageenan	Xanthan	ERS2	Nanocrystalline cellulose	Chitin
Pectin	Cassia seed gum	Laminarin	Dextran	ERS3	Nanofibrillated Cellulose	Chitosan
Inulin	Basil seed gum	Alginate	Skleroglucan	ERS4		
Konjac glucomannan	Oat gum	Fucoidan				
	Psyllium	Red algae				
	Locust bean gum					
	Starch					

Figure 4. Classification of food hydrocolloids (adapted from (Manzoor et al., 2020))

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Tables

Table 1. Prebiotic activities of some common food hydrocolloids

Hydrocolloid	Mechanism of action	Reference
Gum arabic	Averts dysbiosis SCFAs ↑	Al-Asmakh, M., et al 2020
	Clostridium histolyticum ↓ *Bifidobacterium* ↑	Rawi, M.H., et al 2021
Pectin	SCFAs ↑	Mao et al., 2019
	Bacteroides and *Firmicutes* spp. ↑ Metabolic endotoxemia and inflammation↓	Jiang et al. 2016
Inulin	SCFAs ↑ *Bifidobacterium* ↑ Prevents dysbiosis	Tawfick et al., 2022
	Anaerostipes, Faecalibacterium, Lactobacillus ↑	Le Bastard et al., 2020
Birch xylan	Aids the evolution of a slow rate of gas pressure and structure short-chain fatty acids	Rosa-Sibakov et al., 2016
Konjac glucomannan	Boosts the healthy recolonization of vaginal microbiota following infections	Tester et al., 2012
	Butyric acid in the colon ↑	Ariestanti, Seechamnanturakit, Harmayani, & Wichienchot, 2019
Guar gum	Soluble residuum	Ohashi et al., 2015

	SCFAs ↑ Anti-constipation and laxative-like effects	Kapoor et al., 2017
Fenugreek gum	Soluble residuum SCFAs ↑ Averts dysbiosis	Majeed et al., 2018
	Escherichia coli ATCC 25922	Bruce Keller et al., 2020
Cassia seed gum	Acetic and propionic acid ↑ Intestinal pH ↓ *Bifidobacterium, Lactobacillus, Bacteroides, Veillonella* ↑ *Fusobacterium, Lachnospiraceae, Sutterella* ↓	Miao et al., 2021
Basil seed gum	*Pediococcus acidilactici, Enterococcus faecium* ↑ *Lactic acid bacteria* ↑ *Salmonella-Shigella* spp. ↓	Wongputtisin & Khanongnuch, 2015
Oat gum	*Bifidobacterium Bacteroides, Proteobacteria* ↑	Kristek et al., 2019
	Actinobacteria *Firmicutes* ↓	Chappell, Thies, Martin, Flint, & Scott, 2015
Psyllium	SCFA ↑	Jalanka et al., 2019
	Faecalibacterium, Romboutsia, Streptococcus, Bifidobacterium ↑	Yang et al., 2021

	By hydrolyzing fiber, polysaccharides develop into a more digestible form for the production of SCFAs with high butyric acid-concentration, decreasing the pH of the colon and promoting the growth of *Lactobacilli* to preserve gut health.	Yadav, Sharma, Kapila, Malik, & Arora, 2016
Locust bean gum	*Lactobacillus, Bifidobacteria* ↑ *Atopobium* and *Bacteroides* ↓ SCFAs ↑	González-Bermúdez, C., et al.2018
Starch	*Clostridium, Butyricoccus* ↑ *Bacteroides, Lactobacillus, Oscillospira, Ruminococcus* ↓	Zhu et al., 2020
	Bacteroides, Parabacteroides, Oscillospira, Blautia, Ruminococcus, Eubacterium, Christensenella ↑ Butyric, propionic, valeric, isovaleric, hexanoic acid ↑	Upadhyaya et al., 2016
Tamarillo hydrocolloids	Pathogenic bacteria is inhibited with reduced pH during fermentation. However, the declining pH causes the growth of *Bifidobacteria* and *Lactobacilli*.	Gannasin et al., 2015
Seaweeds	The growth of *L. plantarum* is promoted, while the growth of pathogen *Salmonella typhimurium* is suppressed. *Lactobacillus plantarum* ↑	Praveen et al., 2019
Gellan gum	Increases cecum volume, increases stool volume	Kerckhoffs, D.l.A., et al. 2002; Levrat-Verny, M.-A., et al. 2000
Xanthan	Acetate ↑	Lindström, C., et al., 2012
Dextran	SCFAs ↑	Lindström, C., et al., 2012

Scleroglucan	Acetic acid and butyric acid level ↑ Stool volume ↑	Lindström, C., et al., 2012
Modified starch	Boosts lipid profile and body composition by increasing SCFA production	Nichenametla, S.N., et al. 2014; Byrne, C., et al.,2015
Cellulose Derivatives	SCFAs ↑	He, X., et al., 2021
Chitin oligosaccharides	*Bifidobacterium* spp. ↑	Nurhayati, Manaf, Osman, Abdullah, & Tang, 2016
	The bacterial growth of pathogenic microorganisms such as *Enteropatojenik Escherichia coli and Salmonella typhimurium* ↓	Rinninella, E., et al.2019; Benhabiles, M., et al. 2012

SCFAs: Short Chain Fatty Acids