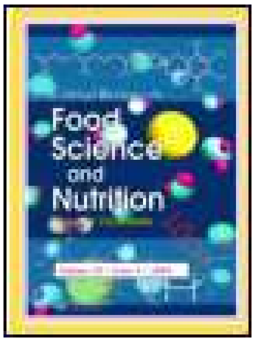

Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Psyllium: a useful functional ingredient in food systems

Mayara Belorio & Manuel Gómez

To cite this article: Mayara Belorio & Manuel Gómez (2020): Psyllium: a useful functional ingredient in food systems, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2020.1822276

To link to this article: https://doi.org/10.1080/10408398.2020.1822276

Published online: 21 Sep 2020.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2020.1822276

REVIEW

Psyllium: a useful functional ingredient in food systems

Mayara Belorio and Manuel Gómez

Food Technology Area, College of Agricultural Engineering, University of Valladolid, Palencia, Spain

ABSTRACT
Psyllium gum is a hydrocolloid found in the husk of seeds from *Plantago ovata*. Psyllium husk has been used in traditional medicine in areas of India and China. Its consumption has been shown to provide nutritional benefits, such as the capacity to reduce the glycaemic index, to minimize the risk of cardiovascular diseases, to decrease cholesterol and constipation problems and others. Thus, interest in the incorporation of psyllium in food products is twofold. First, it can be a natural alternative to the use of other gums and hydrocolloids considered additives. Second, it can be used to improve the nutritional properties of products in which it is incorporated. However, for this purpose, it is necessary to add great quantities of psyllium. This review analyses the potential use of psyllium in distinct food products, considering its advantages and inconveniences as well as possible solutions for undesired effects. Among the analyzed products there are bakery products and, in particular, gluten-free breads where psyllium has been used as a gluten substitute. The incorporation of psyllium into dairy products such as yogurts and those derived from fruits, among others, is also addressed.

KEYWORDS
Psyllium; bakery products; gluten-free; low-fat; health claims

Origin and structure

Seeds from *Plantago ovata*, also known as psyllium or isabgol, have fiber-rich huskwhich is valued for its nutrients and other properties. This plant is native to the Mediterranean region and, nowadays, the main global manufacturer of these seeds is India. There is also a significant production in Pakistan and Iran, from where the seeds are exported worldwide. The main importers are the USA, Germany and the United Kingdom (Golkar, Amooshahi, and Arzani 2017; Sarkar and Lal 2018).

The first scientific article about psyllium is dated from 1927 and, until nowadays, there are over 1200 articles with the word psyllium in the subject, according to Web of Science. From this amount, almost 120 are from before 1995 and they are mainly centered in structural or health aspects. However, the first study about psyllium published in journals, Food Science and Technology category, is dated from 1988. Nevertheless, as observed in figure 1, there is an increasing interest for this topic and the number of articles published in scientific journals has been growing over the last years. These studies have deeply analyzed the functional properties of psyllium and its use in different food products (Table 1). This was because psyllium improves nutritional and organoleptic characteristics of these products. These articles are mostly centered in bakery products, especially in bread (with or without gluten), but there is also a significant number of studies about dairy products (Figure 2).

Psyllium is considered a hydrocolloid because of its functional properties, such as solubility and viscosity. Hydrocolloids are polysaccharides which are composed by many hydroxyl groups that increase their capacity to bind water and to generate viscous solutions (Saha and Bhattacharya 2010). In fact, psyllium viscosity is the responsible for its nutritional benefits, and its high- water absorption capacity is one of the most important properties for its use in food elaboration. Health benefits of different fibers depend on their structure, water absorption capacity and viscosity growth (Capuano 2017; Fuller et al. 2016; Padayachee et al. 2017). In general, it is common to use the term ‘gum’ to name some hydrocolloids. This term is related to their capacity to disperse in water generating a more viscous solution. Likewise, the term mucilage is associated with the viscous material found in the seed husk of some plants, such as the psyllium (Li and Nie 2016).

Different studies found that psyllium is an arabinoxylan most composed by different monosaccharides, such as xylose (Xyl), arabinose (Ara), galactose (Gal), rhamnose (Rha), glucose (Glu) and mannose (Man). The different molar ratio and monosaccharide composition among these polysaccharides can be related to the methods of separation or purification that can be used to obtain the psyllium (Zhang et al. 2019). Most of the soluble fiber present in the psyllium husk is an arabinoxylan similar to those found in most cereals (Izydorczyk and Biliaderis 1995). In fact, the fiber of psyllium and wheat bran is largely composed of highly branched arabinoxylans that consist of linear β-D-(1–>4)-linked xylopyranose (Xylp) backbones to which α-L-arabinofuranose (Araf) units are attached as size residues, via α(1-3) and α(1-2) linkages. Psyllium fiber has a more complex structure than wheat bran fiber, with wide variation in the side chains

CONTACT Mayara Belorio beloriom@gmail.com Food Technology Area, College of Agricultural Engineering, University of Valladolid, 34071 Palencia, Spain

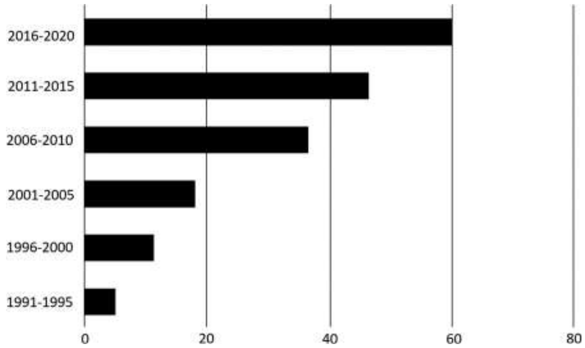

Figure 1. Published articles about the use of psyllium in food science and technology category from the last thirty years. Searching by the word "psyllium" in the topic of articles related with Food Science and Technology, using the research tool of Web of Science. The search was made on May 23th of 2020.

and attached substituents at positions O-2 and/or O-3. These substituents arepredominantly mono-substitution with α-L-Ara *f* or *β*-D-Xyl *p*, a di-substitution with α-L-Ara f, and mono-substitution with oligosaccharides consisting of α-L-Ara f or *β*-D-Xyl p (Edwards et al. 2003; Fischer et al. 2004). It is possible to distinguish many types of arabinoxylans that are similar in monomeric composition, but vary in their polymer conformation (Yin, Lin, et al. 2012; Yu et al. 2017). Thus, mucilage, more easily extracted with cold water, has a high proportion of rhamnose and galacturonic acid, but a low content of arabinose and xylose compared with mucilage obtained under extreme conditions (heat and alkalinity). This cold-extracted mucilage also has a larger molecular weight and a smaller hydrodynamic radius than the others (Yu et al. 2017). Nie, Cui, and Xie (2018) and Zhang et al. (2019) recently presented the last results obtained for different methods of extraction, purification, structural identification and biological activities of psyllium polysaccharides. They also indicated the repeating unit of psyllium polysaccharides obtained through different methods of obtention and identification. However, it was highlighted the lack of studies that analyses psyllium polysaccharides and the relation between their activity and structure.

Nutritional advantages

The nutritional advantages of psyllium have been discussed in multiples scientific articles and include its effects on constipation, diarrhea, irritable bowel syndrome (IBS), inflammatory bowel disease–ulcerative colitis, colon cancer, diabetes and hypercholesterolemia. All these topics were widely discussed in different reviews (Franco et al. 2020; Zhang et al. 2019; Nie, Cui, and Xie 2018; Warnberg et al. 2009; Singh 2007), as the same as the effects of psyllium supplementation on body weight (Mofrad et al. 2020). For this reason, this topic is not deeply analyzed in this review. Some of these properties are related to the viscous character of psyllium, as it is established that the consumption of viscous fibers can alter the viscosity of digesta in the gastrointestinal tract, thereby inhibiting the absorption of nutrients, particularly glucose and cholesterol (Dikeman and Fahey 2006). Some of these properties are briefly discussed in this section.

In the small bowel, clinically meaningful health benefits (cholesterol lowering and improved glycaemic control) are highly correlated with the viscosity of soluble fibers. High-viscosity fibers (gel-forming fibers such as *β*-glucan, psyllium and raw guar gum) significantly lower cholesterol and improve glycaemic control. Non-viscous soluble fibers (inulin, fruit-oligosaccharides and wheat dextrin) and insoluble fibers (wheat bran) do not provide these viscosity-dependent health benefits (McRorie and McKeown 2017). In the large bowel, there are only two mechanisms that promote a laxative effect. One is the mechanical irritations in the gut that are promoted by large/coarse insoluble fiber particles (wheat bran) which stimulate water and mucous secretion. The second one is the resistance to dehydration generated by the high water-holding capacity of gel-forming soluble fiber (psyllium). Both mechanisms require that the fiber resists fermentation and remains relatively intact throughout the large bowel (the fiber must be present in stool). These mechanisms lead to increased stool water content, resulting in bulky/soft/easy-to-pass stools (McRorie and McKeown 2017). Thus, for the treatment of IBS, a common chronic gastrointestinal disorder, many physicians recommend that patients increase their intake of dietary fiber. Nevertheless, the efficiency of individual fiber types at obtaining these results varies widely. The generally preferred long-chain, intermediate viscous, soluble and moderately fermentable dietary fibers, such as psyllium, generate little gas and consequently do not cause the symptoms related to excessive gas production. Thus, psyllium is one of the most recommended fibers for this purpose, and it is both safe and effective at improving IBS symptoms globally (Bijkerk et al. 2004; El-Salhy et al. 2017).

Psyllium is one of the most fiber-rich ingredient among natural products. Together with wheat bran, unlike other types of fibers, it has a defined role in preventing constipation (Gelinas 2013). The effect of psyllium is based on its high water-absorption capacity (as a bulking agent) and gut-stimulatory potential with a lubricating effect. Thus, psyllium can be a more natural alternative treatment for this condition than other products which have demonstrated efficiency, such as polyethylene glycol, tegaserod or lactulose (Ramkumar and Rao 2005).

It has been demonstrated, in many cases, that psyllium husk plays a key role in lowering serum cholesterol, both in humans and in animals. That is whypsyllium is being considered a potential supportive agent in the treatment of hyperlipidemia (Xing et al. 2017). Psyllium can decrease total and low-density-lipoprotein (LDL) cholesterol, as it has been deeply analyzed in several reviews and meta-analyses (Anderson et al. 2000; Bernstein et al. 2013; Olson et al. 1997; Wei et al. 2009). In addition, it can also reduce the glycaemic index in both diabetic and non-diabetic patients (Abutair, Naser, and Hamed 2016; Gibb et al. 2015). This effect is most evident when psyllium is ingested with food and not before a meal (Wolever et al. 1991). However, the consumption of psyllium before bread effectively reduced the glycaemic response (Munari et al. 1998). It was also demonstrated that the ingestion of psyllium decreased

Table 1. Purpose of psyllium addition in researches about different food products.

		Purpose of use					
Product	References	Rheology Control	Anti-staling Effect	Fat Replacer	Gluten Substitute	Nutritional Improvement	Sensory Improvement
Bread	Farbo et al. (2020)	X					
	Pejcz et al. (2018)	X				X	
	Ray et al. (2018)					X	
	Man et al. (2017)					X	
	Sim, Aziah, and Cheng (2015)	X					
	Park, Seib, and Chung (1997)					X	
Gluten-free bread	Ziemichéd et al. (2019)				X		
	Fratelli et al. (2018)				X		
	Aprodu and Banu (2015)					X	
	Collar et al. (2015)				X		
	Mancebo et al. (2015)				X		
	Cappa, Lucisano, and Mariotti (2013)		X		X	X	
	Mariotti et al. (2009)				X	X	
	Zandonadi, Assunção-Botelho, and Coelho-Araújo (2009)				X	X	
	Haque and Morris (1994)				X		
Cakes	Belorio, Sahagún, and Goméz (2019)			X			
	Beikzadeh et al. (2017)		X				
	Beikzadeh et al. (2016)					X	
	Bhise and Kaur (2015)		X				X
Cookie	Zbikowska, Kowalska, and Pieniowska (2018)			X			
	Krystyjan et al. (2018)					X	
	Fradinho, Nunes, and Raymundo (2015)					X	
	Raymundo, Fradinho, and Nunes (2014)					X	
Dairy	Amini, Yousefi, and Moghari (2018)	X					
	Bhat, Deva, and Amin (2018)					X	
	Dello Staffolo, Sato, and Cunha (2017)	X					
	Nami, Haghshenas, and Khosroushahi (2017)	X				X	
	Yadav et al. (2016)					X	
	Ladjevardi, Gharibzahedi, and Mousavi (2015)			X			
Jams, Jellies	Figueroa and Genovese (2020)					X	
	Figueroa and Genovese (2018)					X	
	Lele et al. (2018)					X	
Mayonnaise	Amiri et al. (2014)			X			
Pasta	Peressini et al. (2020)	X				X	
	Foschia et al. (2015a)					X	
	Foschia et al. (2015b)					X	
Pizza	Sen Gupta et al. (2015)					X	

feelings of hunger and energy intake in normal volunteers, which was related to an increase in the time allowed for intestinal absorption (Rigaud et al. 1998).

The effects of psyllium ingestion on cholesterol, glycaemic index and satiety decrease the risk of metabolic syndrome and cardiovascular disease. Therefore, itis recommended to include psyllium in weight loss diets (Jane, McKay, and Pal 2019). In fact, it was also observed that psyllium could improve fat distribution and lipid profiles in an at-risk population of male adolescents (de Bock et al. 2012). Another effect of its ingestion is the reduction of blood pressure in hypertensive and obese subjects (Cicero et al. 2007). Psyllium is one of the most widely used fiber supplements for these purposes, because it is reasonably inexpensive and better tolerated than other fiber supplements (Pal and Radavelli-Bagatini 2012). Based in all these lines of evidence, in the USA, the FDA (Food and Drug Administration) (2018) allowed the inclusion of a health claim on products that contain at least 1.7 g of soluble fiber per reference amount customarily consumed. The text of the claim says that ‘diets that are low in saturated fat and cholesterol and that include soluble fiber from psyllium seed husk “may” or “might” reduce the risk of heart disease’. It specifies the daily dietary intake of soluble fiber that is necessary to reduce the risk of coronary heart disease, which in this case is a minimum of 7 g of psyllium husk per day.

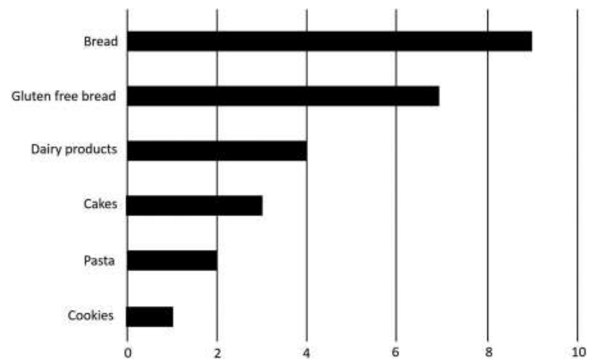

Figure 2. Published articles about psyllium in food products from 2016 to 2020. Searching by "psyllium" and each products name (bread, gluten free bread, dairy, cake, pasta, cookies) in the topic of articles related with Food Science and Technology, using the research tool of Web of Science. For the total studies about "psyllium" and "bread" it was discounted those studies related with "psyllium" and "gluten free bread". The search was made on May 23th of 2020.

The Canadian government authorized the use of a predefined text on the labels of products that contain at least 1.75 g of psyllium, as soluble fiber, per reference amount and per serving of a stated size (Health Canada 2011). The text proposed is as follows: '[serving size from Nutrition Facts table in metric or common household measures] of (Brand name) [name of food] with psyllium supplies/provides X % of the daily amount of the fibers (7 g) shown to help reduce/lower cholesterol'.

In addition to all the nutritional benefits previously mentioned, psyllium was shown to prevent colon cancer, especially when combined with wheat bran (Alabaster et al. 1993). This effect was associated with the fact that colonic anaerobic fermentation of psyllium yields a considerable production of short-chain fatty acids, which play an important role in cancer prevention (Warnberg et al. 2009). Finally, it is important to mention that psyllium has prebiotic effect, such as other arabinoxylans (Slavin 2013). Nevertheless, this effect depends on the arabinoxylan structure. Small differences among the arabinoxylans can change their effect over the microbiota, such as proved with wheat arabinoxylans (Tuncil et al. 2020). However, considering psyllium, more studies are needed to analyze the correlation between psyllium structure and its effect over the gut microbiota.

Functional properties

The incorporation of fibers or hydrocolloids produces changes in food formulation. These changes depend on the functional properties of these ingredients, and some of them can also explain their nutritional advantages. Psyllium can be included among the viscous soluble fibers that thicken when mixed with fluids, such as gums, pectin and β-glucans (Dikeman and Fahey 2006). The greater water-holding capacity of psyllium is one of its most important characteristics. It is 10 times greater than that of cellulose obtained by wheat or bamboo and five times greater than that of apple fiber (Dello Staffolo, Sato, and Cunha 2017). For this reason, psyllium behaves similarly to ydrocolloids.

Haque et al. (1993) and Belorio, Marcondes, and Goméz (2020) compared the capacity of psyllium to form a weak gel with the behavior of xanthan gum. Belorio, Marcondes, and Goméz (2020) showed that gels made with increasing concentrations of psyllium had similar rheological behavior than those elaborated with xanthan gum. Guo et al. (2009) studied the alkaline extracted gel fraction of psyllium polysaccharides. It was confirmed that psyllium forms a weak gel structure after heating, obtaining a fibrillar structure with values of the elastic modulus (G') larger than the viscous modulus (G"), which coincides with the research of Farahnaky et al. (2010) on psyllium gum. Values of G' characterize the solid behavior of the gel and values of G" evaluate the liquid behavior. These investigators also observed that values of G' and G" increased with psyllium gum concentration, showing a shear thinning behavior, similar to the reduction of apparent viscosity with higher frequencies. This behavior coincides with the research of Yin et al. (2016), who studied, without previous heating, the rheological properties of the alkaline-extracted polysaccharide from seeds of *Plantago asiatica*. They showed that higher concentrations of polysaccharide reduced the dependence of the apparent viscosity on frequency and elevated values of G'. When the mixes were heated, the apparent viscosity and its dependence of frequency decreased, whereas a minimum reduction in values of G' and G" was promoted. Indeed, for a temperature of 60 °C, G" was larger than G'. Nevertheless, the extraction method of the polysaccharide must be considered, as it can affect the functionality and structure of the polysaccharide. Thus, cold-extracted mucilage presents a viscoelastic fluid response (tg delta $>$ 1) compared with those obtained in warm or alkaline conditions, which display gel-like behaviors (tg delta $<$ 1) (Yu et al. 2017). The same study proved that G' and G" of cold-extracted mucilage were highly dependent on (increased with) the frequency and this effect was reduced as the force of the extraction increased. G' values decreased with increasing temperature and G' was accentuated around 70–80 °C, which coincides with the temperature of thermogelation from hydroxypropyl methylcellulose (HPMC), so Haque et al. (1993) proposed their use combined as a gluten substitute in bakery products.

It is known that the presence of calcium ions greatly influences the rheological properties of psyllium. Thus, Guo et al. (2009) confirmed that the presence of calcium drastically increased G' values from gels because of a denser structure and thicker strands. In fact, the elimination of calcium from the polysaccharides obtained from *Plantago asiatica* L. promoted a reduction in the intrinsic viscosity, hydrodynamic radius and molecular weight (Yin et al. 2015), and also in the thermic stability (Yin, Nie, et al. 2012). G' values of these gels increased in the presence of sodium ions, but the effect was less pronounced than in presence of calcium ones (Yin et al. 2016). The influence of calcium on the rheological properties of psyllium can be of great importance when it is incorporated into dairy products (Nie, Cui, and Xie 2018). Rheological properties of psyllium gels can be affected by other ingredients present in the solution. The presence of gum Arabic or Z-trim (a corn bio-fiber gum) reduced the viscosity of psyllium gum solutions, while maltodextrins or locust bean gum only modified it. However, the decrease in water holding capacity of psyllium husk was greater in the presence of LBG (Kale, Yadav, and Hanah 2016). The rheology of psyllium gel is also influenced by pH. Values of G' were reduced by acid pH (2.5) and Farahnaky et al. (2010) attributed this to the fact that psyllium gum is an anionic polysaccharide with a negative charge from ionized carboxyl groups. The extension and interaction between molecule chains are induced by electrostatic repulsions and produce intermolecular cross-linking, which causes gelation. However, electrostatic repulsions and the interaction between molecules decrease with a reduction in pH. Another possible explanation for psyllium rheology behavior is related to reduction of the superficial area from psyllium particles promoted by acid treatments (Cheng et al. 2009). In fact, the water uptake capacity and the swelling volume of psyllium are reduced after these treatments, and so psyllium gels are weaker and less adhesive. Similarly, Li et al. (2020) observed that the incorporation of ascorbic acid reduced the apparent viscosity of psyllium solutions, in the same way as it did with other commercial arabinoxylans. Nevertheless, rheological properties of psyllium gels do not present differences in the presence of usual pH from food formulations (4.7 and 10) or these differences are very limited (Farahnaky et al. 2010).

It is known that mostly hydrocolloids present interactions with other food components, such as sugar (Saha and Bhattacharya 2010), starches (BeMiller 2011) or proteins (Syrbe, Bauer, and Klostermeyer 1998). However, there are hardly any articles that study the interactions of psyllium with these components. Li et al. (2020) showed that the incorporation of different sugars, up to 4%, did not affect the apparent viscosity of psyllium solutions. Nevertheless, there are no studies with the use of higher percentages of sugars for different food. Regarding the interactions between psyllium and starch, Belorio, Marcondes, and Goméz (2020) observed a very similar effect to the xanthan gum. The water absorption capacity of the evaluated mixtures increased, such as the rheologic values of the gels, but their hardness decreased. Psyllium is also known to interact with cellulose, but in a greater extend if the cellulose has been fibrillated (Ren, Linter, and Foster 2020). A reduction of celluloses particle size enables this interaction after heating, which generates more compact structures. In the future, interactions between psyllium and other components should be studied to improve the understanding of psyllium functionality in different food products.

The thickening and gelling properties of psyllium can be an advantage in some food recipes, but in certain pharmaceutical formulations, they can be a problem. A similar effect to that obtained with acid treatments can be achieved with enzymatic ones. Yu et al. (2003) reduced the water absorption capacity of psyllium and the hardness of its gels by pre-treating them with an enzymatic combination which included cellulase, hemicellulase, xylanase, arabanase and b-glucanase activities. They observed a decline in superficial area and a less coarse surface on psyllium particles after the enzymatic treatment. Among these enzymes those that act specifically on xylans are the most effective, but a better result could be obtained with a combination of them (Yu and Perret 2003a, 2003b). This enzymatic hydrolysis changed the functional properties of psyllium, but did not reduce its hypolipidemic effects (Allen, Bristow, and Yu 2004). Other chemical modifications of psyllium, such as sulfation, hydroxypropylation and succinylation, also minimized the hardness and adhesiveness of the gels and the swelling capacity of psyllium, but they increased its bile acid-binding capacity. This is important because the binding of bile acids to polymers may enhance their elimination, which promotes the conversion of cholesterol in the liver to bile acids. In addition, it may reduce the total plasma and LDL cholesterol levels and, finally, reduces the risk of cardiovascular diseases (Niu et al. 2013).

Use in bakery products

The greatest application of psyllium in the food industry is in bakery products, especially in gluten-free breads. A study of 228 gluten-free commercial breads, manufactured in different countries, showed that 16% of those products had psyllium as the main gluten substitute (figure 3), and in 34% it was present in formulations. Psyllium was indicated to be the fourth most used hydrocolloid, behind only HPMC, xanthan gum and guar gum (Román, Belorio, and Gómez 2019). Breads made with wheat flour present a gluten network, which is formed by the proteins in the flour after they are hydrated and subjected to mechanical work. This network is responsible for the viscoelastic properties and extensibility of the dough and for retention of the gas produced during fermentation. The incorporation of gums and hydrocolloids as gluten substitutes, to elaborate gluten-free bread, aims to obtain products with volume and texture similar to those from wheat breads (Anton and Artfield 2008; Sciarini et al. 2010). Among these substitutes, HPMC is the most used both in commercial breads and scientific research, followed by xanthan gum (Masure, Fierens, and Delcour 2016, Mir et al. 2016; Román, Belorio, and Gómez 2019). HPMC has the advantage of generating breads with greater volume than other hydrocolloids (Sabanis and Tzia 2011), but these breads have a dryer and more crumbly texture (Liu et al. 2018). For this reason, its common to combine HPMC with other hydrocolloids with higher water retention capacities, such as guar or xanthan gums (Horstmann, Axel, and Arendt 2018).

Psyllium is a natural alternative to other hydrocolloids, and it has nutritional benefits with similar rheological properties to xanthan gum, as showed by Haque et al. (1993). As mentioned earlier, these authors proposed the use of both HPMC and psyllium, because the G' of psyllium doughs decreases at 70–80 °C, which coincides with the thermogelation of HPMC. So, both effects could be compensated during baking. However, the use of psyllium in gluten-free breads is less often studied compared with other hydrocolloids, and it is limited to its combination with HPMC (Haque and Morris 1994; Mancebo et al. 2015) or with other

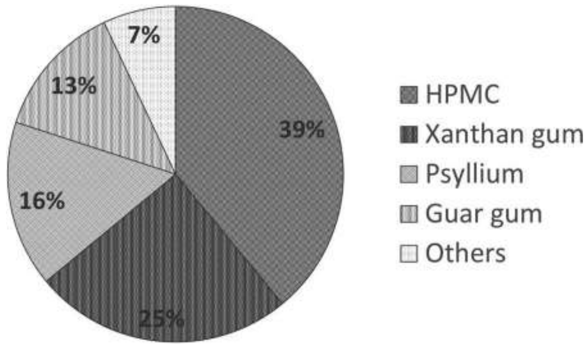

Figure 3. Different hydrocolloids used as the main gluten-substitute to elaborate gluten-free commercial breads. Adapted from Román, Belorio, and Gómez (2019).

gums and fibers (Aprodu and Banu 2015; Cappa, Lucisano, and Mariotti 2013; Collar et al. 2015; Tubili et al. 2016). Zandonadi, Assunção-Botelho, and Coelho-Araújo (2009) produced gluten-free breads with psyllium as a single substitute for gluten and obtained products with good organoleptic characteristics, but other technological characteristics, such as volume or texture, were not measured. Fratelli et al. (2018) demonstrated the effect of psyllium at reducing the glycaemic response in gluten-free breads. In general, the quantity of psyllium used in these studies did not surpass 2%. Fratelli et al. (2018) established an optimum near 2% for the organoleptic quality of breads and incorporated almost 17% psyllium to reduce the glycaemic response. Values of G' and G" increased when psyllium was added to gluten-free doughs, due to its greater thickening properties and water absorption capacity (Collar et al. 2015). As it has been demonstrated, this effect must be considered, that as lower are the consistency of these doughs, the higher is the specific volume of the obtained breads until a certain point in which doughs are weaker and cannot support their structure during fermentation or baking (Mancebo et al. 2017). Fratelli et al. (2018) and Mancebo et al. (2015) demonstrated that it is necessary to increase the hydration of gluten-free bread dough, when psyllium is incorporated in the formulation, to achieve better results for volume and a reduction of hardness in the final breads. Mariotti et al. (2009) proposed a change in dough hydration through farinograph analysis while evaluating gluten-free bread doughs with and without psyllium. They proved that when hydration was changed, values of G' became equal, but G" remained higher compared with doughs with psyllium. In any case, the results about the effect of psyllium on specific volume and texture of breads depend on whether hydration is modified in each formulation and how this modification is made. The incorporation of the whole seed (natural or ground) from Plantago ovata has also been proposed (Ziemichód, Wójcik, and Rózyło 2019). In this study, final breads presented a lower specific volume (less than 2 cm^3/g in all cases), but the use of these seeds improved bread texture (smaller hardness, greater elasticity and cohesiveness).When dough hydration ncreased, a higher yield was achieved. In this case, they used 5% of seeds, as a proportion of total flour used in the formulation, which was greater than the amount analyzed in other studies using psyllium husk or psyllium gum.

Hydrocolloids do not play an important role in gluten-containing breads as they do in gluten-free breads, but they can help to improve their final quality. The incorporation of hydrocolloids allows an increase in dough hydration and can promote greater stability during fermentation. In addition, it allow better moisture retention during baking and improve the specific volume of final breads (Rosell, Rojas, and de Barber 2001). In the same way, hydrocolloids can reduce moisture loss during storage, preventing staleness and retarding crumb hardening (Davidou et al. 1996; Guarda et al. 2004). This anti- staling effect was also observed in par-baked breads (Barcenas and Rosell 2007). It is possible to obtain these effects using a small quantity of hydrocolloids, less than 0.5%, depending on the type of hydrocolloid used. The use of psyllium with other hydrocolloids improved the absorption of the dough and the mixing time, which produced strongest doughs (Czuchajowska, Paszczynska, and Pomeranz 1992). The incorporation of psyllium has also been shown to increase the extensibility and the gas retention capacity of doughs, similar to xanthan gum (Farbo et al. 2020). Although, the effects of psyllium on bread volume are not uniform and depend on the formulation or the type of flour used. Different studies concede that the use of psyllium promotes breads with greater moisture, less dry during baking,softer texture and less staling (Czuchajowska, Paszczynska, and Pomeranz 1992; Park, Seib, and Chung 1997). This effect has also been proven in steamed breads (Sim, Aziah, and Cheng 2015). However, Jensen et al. (2015) obtained different results, because psyllium significantly reduced the volume of breads and increased their hardness. Nevertheless, this study did not change the hydration of the doughs as function of previous analyses by farinograph or mixograph, which indicates the huge importance of this correction, because of the influence of psyllium over water absorption. In general, studies about the use of psyllium are limited by its use in small percentages, not greater than 1%. However, it is convenient to use a greater quantity of psyllium to achieve its nutritional benefits in final products. There are limited studies that show this property, and it was proven that increasing the percent incorporation of psyllium (15%), raises the moisture of the breads by more than 25%, but reduces the specific volume by 37% (Man et al. 2017). It is important to mention that the study did not specify the formulation, or the characteristics of the wheat flour used. Pejcz et al. (2018) observed that the incorporation of 8% of psyllium husk promoted an increase in bread volume, with no significant difference in acceptability between these breads and the control. It is important to notice that they used doughs with a consistency of 300 Brabender FU, which is smaller than other studies (500 FU). It indicates the necessity of conducting new studies to prove these differences. More studies are also required with respect to the correct percentage of psyllium needed to achieve an effective reduction of the glycaemic index of breads. Ray et al. (2018) proved that a significant reduction in rapidly digestible starch. An increase in both slowly digestible starch and resistant starch was obtained when 25% of wheat flour was substituted by a combination of psyllium, chichpea flour and fenugreek seed powder (7.5% of the total flour weight)in parotta bread. In the same way, it has been proven that the incorporation of psyllium can reduce the glycaemic index of pastas (Peressini et al. 2020). The use of ground psyllium seeds instead of psyllium husk reduced the volume and final moisture of breads, since this effect is related to psyllium gum that is found in the husk. Besides that, psyllium seeds have greater polyphenol levels and antioxidant capacity, so when using the seeds, it is possible to improve these factors in the final product (Pejcz et al. 2018).

The use of 5% psyllium has also been proposed to substitute hydrogenated fat, in the form of canola oil, in pizza dough enriched with protein (Sen Gupta et al. 2015). However, this modification decreased the spread ratio and the organoleptic quality of pizzas. The authors suggested to improve the formulation with additives (SSL and gluten) and enzymes (amylases and proteases).

The use of 3–20% psyllium was suggested in cookie recipes (Fradinho, Nunes, and Raymundo 2015; Krystyjan et al. 2018; Raymundo, Fradinho, and Nunes 2014). In general, the higher the psyllium content in the formula, the greater the values of G', G" and dough hardness, which is related to the thickening power of psyllium. The use of psyllium produced cookies with higher spread ratio, which may be related to the competition with gluten for the limited water available, since a strong gluten decreases cookie expansion during baking (Pareyt and Delcour 2008). Finally, it was observed that cookies with psyllium were darker than those without it, and the results regarding texture were inconsistent. Fradinho, Nunes, and Raymundo (2015) found a clear increase in the hardness of cookies with up to 9% psyllium incorporated into the formulation. Raymundo, Fradinho, and Nunes (2014) confirmed that up to 10% psyllium incorporation could decrease hardness and they obtained similar values with higher percentages, respect to the control. However, Krystyjan et al. (2018) found a reduction in the hardness of cookies with psyllium. The different formulations or ways to measure the hardness could influence the attainment of these distinct results, because although all these studies conducted the penetration test, the probes utilized had different diameters. In contrast to these works, Zbikowska, Kowalska, and Pieniowska (2018) proposed the use of psyllium with microcrystalline cellulose to partially substitute fat in cookie formulations. However, the cookies presented higher hardness and lower acceptability than the control. Similar results were found when the same percentage of fat (25%) was substituted by wheat flour.

Small percentages (1%) of gums with similar characteristics to psyllium, such as xanthan gum, can improve the organoleptic properties of cakes and minimize moisture loss and hardness during storage (Gómez et al. 2007). Studies about using psyllium in batters are scarce and, in general, the incorporated air and the specific volume were reduced, cake crumbs became darker and hardness increased, when more than 5% of psyllium was used, which may be related to less expansion during baking (Beikzadeh et al. 2016; Bhise and Kaur 2015). However, the use of small percentages (1%), can reduce staleness, similarly as the xanthan gum (Beikzadeh et al. 2017). Other authors used a mix of psyllium and water to reduce the oil content in cakes (Belorio, Sahagún and Gómez 2019). Although replacing oil with a combination of psyllium and water reduced the cakes volume, the sample with 75% of oil replacement had high acceptability, 6.99 out of 9, while the control cake had a score of 7.45.Nevertheless, new studies are necessary to expand the information about how to modify formulations whilst minimizing negatives changes. It could also be interesting to study the possibility of substituting oil and fat of these products by using psyllium, since some studies have proposed the use of other gums with similar properties to those of psyllium, such as xanthan gum or β-glucan, to achieve this purpose (Kalinga and Mishra 2009; Lee, Kim, and Inglett 2005).

Use in other systems

As mentioned earlier, hydrocolloids have been used as fat substitutes in different food formulations because of their capacity to retain water (Peng and Yao 2017). In the case of mayonnaises, the use of different hydrocolloids with similar properties to those of psyllium, such as xanthan gum, was proposed to substitute oil in the formulations (Ma and Barbosa-Canovas 1995; Su et al. 2010). In the same way, the incorporation of psyllium as oil substitute was proved to be positive if the correct quantity and percentage substitution (up to 50%) are used. It was possible to obtain products with similar rheological properties to the original one, without differences with respect to acceptability (Amiri et al. 2014).

The addition of 15% psyllium to pastes was evaluated for its ability to reduce the predicted glycaemic response. A reduction greater than 50% was achieved, in accordance with the results obtained for oat bran (Foschia et al. 2015b). This incorporation resulted in darker pastas and increased both cooking time and cooking loss, but decreased the breaking strength, besides improving the absorption of water during cooking (Foschia et al. 2015a). These changes were related to some psyllium properties such as its dark color, and greater water absorption capacity, but also to the lower content of gluten in pastas. It was possible to use combinations of psyllium with inulin of low polymerization to achieve pastas with similar fiber percentages whilst minimizing undesired modifications In this case, the influence of psyllium over the predicted glycaemic response was reduced. In contrast, to maintain this effect on the glycaemic response, it was necessary to use an inulin with a higher polymerization number,however, the changes in the pasta were maintained.

Food hydrocolloids are used in a variety of manufactured dairy products, especially in low-fat ones, as stabilizers and thickening or gelling agents (Hansen 1994). The use of psyllium in these products has been proposed for specific purposes. In gelled dairy desserts, it was used to improve the texture of sugar-free products, producing a final texture similar to that of the reference sample (creamy sensation and gelatinous character), but with poor evaluation results for taste and global acceptability, when compared with other fibers (Dello Staffolo, Sato, and Cunha 2017). Similarly to mayonnaises, the addition of psyllium to yogurts has been studied in formulations of low-fat products (Ladjevardi, Gharibzahedi, and Mousavi 2015), due to its demonstrated effect . to increase the viscosity and to reduce the syneresis. In the same way, quantities of psyllium lower than 1% could improve the quality of Kash, an Iranian ethnic acid-fermented dairy product. Psyllium increased the viscosity, reduced syneresis and the separation of phases, and promoted better organoleptic characteristics, when the correct percentage of this fiber was used (Amini, Yousefi, and Moghari 2018). In fact, the addition of an excessive amount of psyllium to these types of products could lead to undesirable effects on the organoleptic quality of yogurts, as proven by Bhat, Deva, and Amin (2018). In this way, if the purpose is to improve the nutritional characteristics of the product, and it is necessary to add a greater quantity of psyllium, it is better to use hydrolyzed psyllium, which has a lower thickening effect (Yadav et al. 2016). These authors proved that this hydrolysis did not decrease the hypocholesterolemic potential of yogurts enriched with psyllium, and increased its prebiotic effect.

The addition of psyllium to improve the nutritional properties of jams with pectin was studied, and it greatly reduced syneresis, promoting an excessively gummy texture of the final product (Figueroa and Genovese 2018). Similar results were observed in apple jellies (Figueroa and Genovese 2020). So, it is recommended that psyllium be combined with other cellulosic fibers to improve the fiber content of these products. In the same way, the use of psyllium was proposed in gummy supplements because of its prebiotic effect, although it could modify the organoleptic characteristics of the final product (Lele et al. 2018). Because of this prebiotic effect, psyllium has also been proposed in combination with alginate to co-encapsulate probiotic bacteria, generating products with higher encapsulation yields and greater stability than other prebiotics (Peredo et al. 2016). In addition, psyllium improved the stability of these encapsulated materials when pH was reduced, which can be of interest to application in acidic products, such as yogurts (Nami, Haghshenas, and Khosroushahi 2017). Finally, there is a possibility of using psyllium in formulations to obtain biodegradable films with increased tensile strength and thermostability,but reduced water vapor permeability and solubility (Askari et al. 2018; Krystyjan et al. 2017; Sukhija, Singh, and Riar 2016).

Dysphagia is the medical term for difficulty swallowing. Thickened liquids are often used in the management of dysphagia to improve bolus control and to help prevent aspiration (Cichero 2013). To obtain these products, it is common to employ gums or starches. Among these, the use of xanthan gum has been proposed (Kim et al. 2017), as it has similar characteristics to those of psyllium. In fact, psyllium has been used in commercial blends, and it was demonstrated that the combination of psyllium with gellan gum yielded products with superior sensory properties, compared with gellan gum alone (Ishihara et al. 2011a).It increased the structural homogeneity of the bolus and the miscibility with saliva (Ishihara et al. 2011b). This product could be mixed with distinct quantities of water to achieve different consistencies and mouthfeel (Yokoyama et al. 2014).

Conclusion and future perspectives

Psyllium is a natural hydrocolloid with proven nutritional advantages and health benefits. Due to its natural character it can replace other hydrocolloids in clean label products. Psyllium structure corresponds to an arabinoxylan, but its properties are very similar to those of xanthan gum. Nevertheless, psyllium thickener property and water absorption capacity may be reduced by acid or enzymatic hydrolysis. Such as xanthan gum, it has been used for the preparation of gluten-free breads, as a gluten substitute, and it can be incorporated into wheat breads to increase water absorption. The high-water absorption capacity of psyllium also allows its use in distinct formulation to reduce their fat content or water syneresis. In addition, it can be used in other products due to its capacity to reduce the glycaemic index and for its general health properties. Nevertheless, it should be noted that it can provide an excessively gummy texture in some cases. Unlike what happen to other hydrocolloids, there are few studies about the interactions between psyllium and other food components, such as sugars, starches, fibers or proteins. It will be necessary studies addressing these topics, so we understand better the influence of psyllium in different food formulations. It is also important to analyze deeply the relations between psyllium structure, health benefits and functional properties. Thus, it should be studied a way to minimize the undesired effects of great incorporation of psyllium in food, but without reducing its nutritional advantages.

Disclosure statement

The authors of this study certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Funding

The authors are grateful to FEDER-Interreg España-Portugal programme for financial support through the project TRANSCOLAB (0612_TRANS_CO_LAB_2_P).

References

Abutair, A. S., I. A. Naser, and A. T. Hamed. 2016. Soluble fibres from psyllium improve glycaemic response and body weight among diabetes type 2 patients (randomized control trial). *Nutrition Journal* 15 (1):86. doi: 10.1186/s12937-016-0207-4.

Alabaster, O., Z. C. Tang, A. Frost, and N. Shivapurkar. 1993. Potential synergism between wheat bran and psyllium – Enhanced inhibition of colon-cancer. *Cancer Letters* 75 (1):53–8. doi: 10.1016/0304-3835(93)90207-P.

Allen, K. G. D., S. J. Bristow, and L. L. Yu. 2004. Hypolipidemic effects of modified psyllium preparations. *Journal of Agricultural and Food Chemistry* 52 (16):4998–5003. doi: 10.1021/jf0497206.

Amini, S., S. Yousefi, and A. A. Moghari. 2018. Development and quality characterization of liquid Kashk by incorporating psyllium (Plantago ovata Forsk) hydrocolloid gel. *Journal of Food Measurement and Characterization* 12 (3):1669–77. doi: 10.1007/s11694-018-9782-8.

Amiri, S. S., M. Aalami, S. B. Geefan, and A. Ranjbar. 2014. Application of Isfarzeh seed (*Plantago ovate* L.) mucilage as a fat mimetic in mayonnaise. *Journal of Food Science and Technology* 51 (10):2748–54. doi: 10.1007/s13197-012-0796-7.

Anderson, J. W., L. D. Allgood, A. Lawrence, L. A. Altringer, G. R. Jerdack, D. A. Hengehold, and J. G. Morel. 2000. Cholesterol-lowering effects of psyllium intake adjunctive to diet therapy in men and women with hypercholesterolemia: Meta-analysis of 8 controlled trials. *The American Journal of Clinical Nutrition* 71 (2):472–9. doi: 10.1093/ajcn/71.2.472.

Anton, A. A., and S. D. Artfield. 2008. Hydrocolloids in gluten-free breads: A review. *International Journal of Food Sciences and Nutrition* 59 (1):11–23. doi: 10.1080/09637480701625630.

Aprodu, I., and I. Banu. 2015. Influence of dietary fiber, water, and glucose oxidase on rheological and baking properties of maize based gluten-free bread. *Food Science and Biotechnology* 24 (4):1301–7. doi: 10.1007/s10068-015-0167-z.

Askari, F., E. Sadeghi, R. Mohammadi, M. Rouhi, M. Taghizadeh, M. H. Shirgardoun, and M. Kariminejad. 2018. The physicochemical and structural properties of psyllium gum/modified starch composite edible film. *Journal of Food Processing and Preservation* 42 (10):e13715. doi: 10.1111/jfpp.13715.

Barcenas, M. E., and C. M. Rosell. 2007. Different approaches for increasing the shelf life of partially baked bread: Low temperatures and hydrocolloid addition. *Food Chemistry* 100 (4):1594–601. doi: 10.1016/j.foodchem.2005.12.043.

Beikzadeh, S., S. H. Peighardoust, M. Beikzadeh, M. Asghari Javar-Abadi, and A. Homayouni-Rad. 2016. Effect of psyllium husk on physical, nutritional, sensory, and staling properties of dietary prebiotic sponge cake. *Czech Journal of Food Sciences* 34 (No. 6):534–40. doi: 10.17221/551/2015-CJFS.

Beikzadeh, S., S. H. Peighambardoust, A. Homayouni-Rad, and M. Beikzadeh. 2017. Effects of psyllium and marve seed mucilages on physical, sensory and staling properties of sponge cake. *Journal of Agricultural Science and Technology* 19:1079–89.

Belorio, M., M. Sahagún, and M. Goméz. 2019. Psyllium as a fat replacer in layer cakes: Batter characteristics and cake quality. *Food and Bioprocess Technology* 12 (12):2085–92. doi: 10.1007/s11947-019-02362-3.

Belorio, M., G. Marcondes, and M. Goméz. 2020. Influence of psyllium versus xanthan gum in starch properties. *Food Hydrocolloids* 105:105843. doi: 10.1016/j.foodhyd.2020.105843.

BeMiller, J. N. 2011. Pasting, paste, and gel properties of starch-hydrocolloid combinations. *Carbohydrate Polymers* 86 (2):386–423. doi: 10.1016/j.carbpol.2011.05.064.

Bernstein, A. M., B. Titgemeier, K. Kirkpatrick, M. Golubic, and M. F. Roizen. 2013. Major cereal grain fibers and psyllium in relation to cardiovascular health. *Nutrients* 5 (5):1471–87. doi: 10.3390/nu5051471.

Bhat, S. V., A. M. Deva, and T. Amin. 2018. Physicochemical and textural properties of yogurt fortified with psyllium (*Plantago ovata*) husk. *Journal of Food Processing and Preservation* 42 (2):e13425. doi: 10.1111/jfpp.13425.

Bhise, S., and A. Kaur. 2015. Fortifying muffins with psyllium husk fibre, oat fibre and barley fibre to improve quality and shelf life. *Carpathian Journal of Food Science and Technology* 7 (2):5–16.

Bijkerk, C. J., J. W. M. Muris, J. A. Knottnerus, A. W. Hoes, and N. J. De Wit. 2004. Systematic review: The role of different types of fibre in the treatment of irritable bowel syndrome. *Alimentary Pharmacology & Therapeutics* 19 (3):245–51. doi: 10.1111/j.0269-2813.2004.01862.x.

Cappa, C., M. Lucisano, and M. Mariotti. 2013. Influence of Psyllium, sugar beet fibre and water on gluten-free dough properties and bread quality. *Carbohydrate Polymers* 98 (2):1657–66. doi: 10.1016/j.carbpol.2013.08.007.

Capuano, E. 2017. The behavior of dietary fiber in the gastrointestinal tract determines its physiological effect. *Critical Reviews in Food Science and Nutrition* 57 (16):3543–64. doi: 10.1080/10408398.2016.1180501.

Cheng, Z. H., J. Blackford, Q. Wang, and L. L. Yu. 2009. Acid treatment to improve psyllium functionality. *Journal of Functional Foods* 1 (1):44–9. doi: 10.1016/j.jff.2008.09.007.

Cicero, A. F., G. Derosa, M. Manca, M. Bove, C. Borghi, and A. V. Gaddi. 2007. Different effect of psyllium and guar dietary supplementation on blood pressure control in hypertensive overweight patients: A six-month, randomized clinical trial. *Clinical and Experimental Hypertension (New York, N.Y. : 1993)* 29 (6):383–94. doi: 10.1080/10641960701578378.

Cichero, J. A. 2013. Thickening agents used for dysphagia management: Effect on bioavailability of water, medication and feelings of satiety. *Nutrition Journal* 12 (1):12–54. doi: 10.1186/1475-2891-12-54.

Collar, C., P. Conte, C. Fadda, and A. Piga. 2015. Gluten-free dough-making of specialty breads: Significance of blended starches, flours and additives on dough behaviour. *Food Science and Technology International = Ciencia y Tecnologia de Los Alimentos Internacional* 21 (7):523–36. doi: 10.1177/1082013214552862.

Czuchajowska, Z., B. Paszczynska, and Y. Pomeranz. 1992. Functional-properties of psyllium in wheat-based products. *Cereal Chemistry* 69:516–20.

Davidou, S., M. Le Meste, E. Debever, and D. Bekaert. 1996. A contribution to the study of staling of white bread: Effect of water and hydrocolloid. *Food Hydrocolloids* 10 (4):375–83. doi: 10.1016/S0268-005X(96)80016-6.

de Bock, M., J. G. B. Derraik, C. M. Brennan, J. B. Biggs, G. C. Smith, D. Cameron-Smith, C. R. Wall, and W. S. Cutfield. 2012. Psyllium supplementation in adolescents improves fat distribution & lipid profile: A randomized, participant-blinded, placebo-controlled, crossover trial. *PLOS One* 7:7.

Dello Staffolo, M., A. C. K. Sato, and R. L. Cunha. 2017. Utilization of plant dietary fibres to reinforce low-calorie dairy dessert structure. *Food and Bioprocess Technology* 10 (5):914–25. doi: 10.1007/s11947-017-1872-9.

Dikeman, C. L., and G. C. Fahey. 2006. Viscosity as related to dietary fiber: A review. *Critical Reviews in Food Science and Nutrition* 46 (8):649–63. doi: 10.1080/10408390500511862.

Edwards, S., Chaplin, M. F. A. D. Blackwood, P. W. Dettmar. and P. W. 2003. Primary structure of arabinoxylans of ispaghula husk and wheat bran. *The Proceedings of the Nutrition Society* 62 (1):217–22. doi: 10.1079/pns2003202.

El-Salhy, M., S. O. Ystad, T. Mazzawi, and D. Gundersen. 2017. Dietary fiber in irritable bowel syndrome (Review). *International Journal of Molecular Medicine* 40 (3):607–13. doi: 10.3892/ijmm.2017.3072.

Farbo, M. G., C. Fadda, S. Marceddu, P. Conte, A. Del Caro, and A. Piga. 2020. Improving the quality of dough obtained with old durum wheat using hydrocolloids. *Food Hydrocolloids* 101:105467. doi: 10.1016/j.foodhyd.2019.105467.

FDA. USA Food and Drug Administration. 2018. CFR - Code of Federal Regulations, title 21, volume 2.

Figueroa, L. E., and D. B. Genovese. 2018. Pectin gels enriched with dietary fibre for the Development of Healthy Confectionery Jams. *Food Technology and Biotechnology* 56 (3):441–53. doi: 10.17113/ftb.56.03.18.5641.

Figueroa, L. E., and D. B. Genovese. 2020. Structural and sensory analysis of compositionally optimized apple jellies enriched with dietary fibre compared to commercial apple jams. *Journal of Food Science and Technology* 57 (5):1661–70. doi: 10.1007/s13197-019-04199-2.

Fischer, M. H., N. X. Yu, G. R. Gray, J. Ralph, L. Anderson, and J. A. Marlett. 2004. The gel-forming polysaccharide of psyllium husk (*Plantago ovata* Forsk). *Carbohydrate Research* 339 (11):2009–17. doi: 10.1016/j.carres.2004.05.023.

Farahnaky, A., H. Askari, M. Majzoobi, and G. Mesbahi. 2010. The impact of concentration, temperature and pH on dynamic rheology of psyllium gels. *Journal of Food Engineering* 100 (2):294–301. doi: 10.1016/j.jfoodeng.2010.04.012.

Foschia, M., D. Peressini, A. Sensidoni, M. A. Brennan, and C. S. Brennan. 2015a. How combinations of dietary fibres can affect physicochemical characteristics of pasta. *Lwt - Food Science and Technology* 61 (1):41–6. doi: 10.1016/j.lwt.2014.11.010.

Foschia, M., D. Peressini, A. Sensidoni, M. A. Brennan, and C. S. Brennan. 2015b. Synergistic effect of different dietary fibres in pasta on in vitro starch digestion?. *Food Chemistry* 172:245–50. doi: 10.1016/j.foodchem.2014.09.062.

Fradinho, P., M. C. Nunes, and A. Raymundo. 2015. Developing consumer acceptable biscuits enriched with Psyllium fibre. *Journal of Food Science and Technology* 52 (8):4830–40. doi: 10.1007/s13197-014-1549-6.

Franco, E. A. N., A. Sanches-Silva, R. Ribero-Santos, and N. R. de Melo. 2020. Psyllium (Plantago ovata Forsk): From evidence of health benefits to its food application. *Trends in Food Science & Technology* 96:166–75.

Fratelli, C., D. G. Muniz, F. G. Santos, and V. D. Capriles. 2018. Modelling the effects of psyllium and water in gluten-free bread: An approach to improve the bread quality and glycemic response. *Journal of Functional Foods* 42:339–45. doi: 10.1016/j.jff.2018.01.015.

Fuller, S., E. Beck, H. Salman, and L. Tapsell. 2016. New horizons for the study of dietary fibre and health: A review. *Plant Foods for Human Nutrition* 71 (1):1–12. doi: 10.1007/s11130-016-0529-6.

Gelinas, P. 2013. Preventing constipation: A review of the laxative potential of food ingredients. *International Journal of Food Science and Technology* 48:445–67.

Gibb, R. D., J. W. McRorie, D. A. Russell, V. Hasselblad, and D. A. D'Alessio. 2015. Psyllium fibre improves glycaemic control proportional to loss of glycaemic control: A meta-analysis of data in euglycemic subjects, patients at risk of type 2 diabetes mellitus, and patients being treated for type 2 diabetes mellitus. *The American Journal of Clinical Nutrition* 102 (6):1604–14. doi: 10.3945/ajcn.115.106989.

Golkar, P., F. Amooshahi, and A. Arzani. 2017. The effects of salt stress on physio-biochemical traits, total phenolic and mucilage content of Plantago ovata Forsk under in vitro conditions. *Journal of Applied Botany and Food Quality* 90:224–31.

Gómez, M., F. Ronda, P. A. Caballero, C. A. Blanco, and C. M. Rosell. 2007. Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. *Food Hydrocolloids* 21 (2):167–73. doi: 10.1016/j.foodhyd.2006.03.012.

Guarda, A., C. M. Rosell, C. Benedito, and M. J. Galotto. 2004. Different hydrocolloids as bread improvers and anti-stalling agents. *Food Hydrocolloids.* 18 (2):241–7. doi: 10.1016/S0268-005X(03)00080-8.

Guo, Q., S. W. Cui, Q. Wang, H. D. Goff, and A. Smith. 2009. Microstructure and rheological properties of psyllium polysaccharide gel. *Food Hydrocolloids* 23 (6):1542–7. doi: 10.1016/j.foodhyd.2008.10.012.

Hansen, P. M. T. 1994. Food hydrocolloids in the dairy industry. In *Food hydrocolloids: structures, properties, and functions*, ed. K. Nishinari and E. Doi, 211–24.New York: Plenum Press.

Haque, A., and E. R. Morris. 1994. Combined use of ispaghula and HPMC to replace or augment gluten in breadmaking. *Food Research International* 27 (4):379–93. doi: 10.1016/0963-9969(94)90194-5.

Haque, A., R. K. Richardson, E. R. Morris, and I. C. M. Dea. 1993. Xanthan-like weak gel rheology from dispersions of ispaghula seed husk. *Carbohydrate Polymers* 22 (4):223–32. doi: 10.1016/0144-8617(93)90124-M.

Health Canada. 2011. Psyllium products and blood cholesterol lowering. Summary of Health Canada's assessment of a health claim about food products containing psyllium and blood cholesterol lowering. https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/fn-an/alt_formats/pdf/label-etiquet/claims-reclam/assess-evalu/psyllium-cholesterol-eng.pdf

Horstmann, S. W., C. Axel, and E. K. Arendt. 2018. Water absorption as a prediction tool for the application of hydrocolloids in potato starch-based bread. *Food Hydrocolloids* 81:129–38. doi: 10.1016/j.foodhyd.2018.02.045.

Ishihara, S., M. Nakauma, T. Funami, S. Odake, and K. Nishinari. 2011a. Swallowing profiles of food polysaccharide gels in relation to bolus rheology. *Food Hydrocolloids* 25 (5):1016–24. doi: 10.1016/j.foodhyd.2010.09.022.

Ishihara, S., M. Nakauma, T. Funami, S. Odake, and K. Nishinari. 2011b. Viscoelastic and fragmentation characters of model bolus from polysaccharide gels after instrumental mastication. *Food Hydrocolloids* 25 (5):1210–8. doi: 10.1016/j.foodhyd.2010.11.008.

Izydorczyk, M. S., and C. G. Biliaderis. 1995. Cereal arabinoxylans: Advances in structure and physicochemical properties. *Carbohydrate Polymers* 28 (1):33–48. doi: 10.1016/0144-8617(95)00077-1.

Jane, M., J. McKay, and S. Pal. 2019. Effects of daily consumption of psyllium, oat bran and polyGlycopleX on obesity-related disease risk factors: A critical review. *Nutrition (Burbank, Los Angeles County, Calif.)* 57:84–91. doi: 10.1016/j.nut.2018.05.036.

Jensen, S., L. H. Skibsted, U. Kidmose, and A. K. Thybo. 2015. Addition of cassava flours in bread-making: Sensory and textural evaluation. *Lwt - Food Science and Technology* 60 (1):292–9. doi: 10.1016/j.lwt.2014.08.037.

Kale, M. S., M. P. Yadav, and K. A. Hanah. 2016. Suppression of psyllium husk suspension viscosity by addition of water soluble polysaccharides. *Journal of Food Science* 81 (10):E2476–E2483. doi: 10.1111/1750-3841.13438.

Kalinga, D., and V. K. Mishra. 2009. Rheological and physical properties of low-fat cakes produced by addition of cereal Beta glucan concentrates. *Journal of Food Processing and Preservation* 33 (3):384–400. doi: 10.1111/j.1745-4549.2008.00260.x.

Kim, H., H. I. Hwang, K. W. Song, and J. Lee. 2017. Sensory and rheological characteristics of thickened liquids differing concentrations of a xanthan gum-based thickener. *Journal of Texture Studies* 48 (6):571–85. doi: 10.1111/jtxs.12268.

Krystyjan, M., D. Gumul, A. Korus, J. Korus, and M. Sikora. 2018. Physicochemical properties and sensory acceptance of biscuits fortified with Plantago psyllium flour. *Emirates Journal of Food and Agriculture* 30:758–63. doi: 10.9755/ejfa.2018.v30.i9.1799.

Krystyjan, M., G. Khachatryan, W. Ciesielski, K. Buksa, and M. Sikora. 2017. Preparation and characteristics of mechanical and functional properties of starch/Plantago psyllium seeds mucilage films. *Starch-Stärke* 69:11–2.

Ladjevardi, Z. S., S. M. T. Gharibzahedi, and M. Mousavi. 2015. Development of a stable low-fat yogurt gel using functionality of psyllium (Plantago ovata Forsk) husk gum. *Carbohydrate Polymers* 125:272–80. doi: 10.1016/j.carbpol.2015.02.051.

Lee, S., S. Kim, and G. E. Inglett. 2005. Effect of shortening replacement with oat trim on the physical and rheological properties of cakes. *Cereal Chemistry Journal* 82 (2):120–4. doi: 10.1094/CC-82-0120.

Lele, V., M. Ruzauskas, P. Zavistanaviciute, R. Laurusiene, G. Rimene, D. Kiudulaite, J. Tomkeviciute, J. Nemeikstyte, R. Stankevicius, and E. Bartkiene. 2018. Development and characterization of the gummy-supplements, enriched with probiotics and prebiotics. *Cyta - Journal of Food* 16 (1):580–7. doi: 10.1080/19476337.2018.1433721.

Li, J. M., and S. P. Nie. 2016. The functional and nutritional aspects of hydrocolloids in foods. *Food Hydrocolloids* 53:46–61. doi: 10.1016/j.foodhyd.2015.01.035.

Li, O. Y., L. Wang, X. Y. Liu, J. Y. Yin, and S. P. Nie. 2020. Interactions between ascorbic acid and water soluble polysaccharide from the seeds of *Plantago asiatica* L.: Effects on polysaccharide physicochemical properties and stability. *Food Hydrocolloids* 99:105351. UNSP 105351. doi: 10.1016/j.foodhyd.2019.105351.

Liu, X. L., T. H. Mu, H. N. Sun, M. Zhang, J. W. Chen, and M. L. Fauconnier. 2018. Influence of different hydrocolloids on dough thermo-mechanical properties and in vitro starch digestibility of gluten-free steamed bread based on potato flour. *Food Chemistry* 239:1064–74. doi: 10.1016/j.foodchem.2017.07.047.

Ma, L., and G. V. Barbosa-Canovas. 1995. Rheological characterization of mayonnaise. Part II: Flow and viscoelastic properties at different oil and xanthan gum concentrations. *Journal of Food Engineering* 25 (3):409–25. doi: 10.1016/0260-8774(94)00010-7.

Man, S., A. Paucean, S. Muste, A. Pop, and E. A. Muresan. 2017. Influence of Psyllium husk (Plantago ovata) on Bread Quality. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology* 74 (1):33–4. doi: 10.15835/buasvmcn-fst:12631.

Mancebo, C. M., M. M. Martinez, C. Merino, E. de la Hera, and M. Gomez. 2017. Effect of oil and shortening in rice bread quality: Relationship between dough rheology and quality characteristics. *Journal of Texture Studies* 48 (6):597–606. doi: 10.1111/jtxs.12270.

Mancebo, C. M., M. A. San Miguel, M. M. Martinez, and M. Gomez. 2015. Optimisation of rheological properties of gluten-free doughs with HPMC, psyllium and different levels of water. *Journal of Cereal Science* 61:8–15. doi: 10.1016/j.jcs.2014.10.005.

Mariotti, M.,. M. Lucisano, M. A. Pagani, and P. K. W. Ng. 2009. The role of corn starch, amaranth flour, pea isolate, and Psyllium flour on the rheological properties and the ultrastructure of gluten-free doughs. *Food Research International* 42 (8):963–75. doi: 10.1016/j.foodres.2009.04.017.

Masure, H. G., E. Fierens, and J. A. Delcour. 2016. Current and forward-looking experimental approaches in gluten-free bread making research. *Journal of Cereal Science* 67:92–111. doi: 10.1016/j.jcs.2015.09.009.

McRorie, J. W., and N. M. McKeown. 2017. Understanding the physics of functional Fibers in the Gastrointestinal Tract: An evidence-based approach to resolving enduring misconceptions about insoluble and soluble fiber . *Journal of the Academy of Nutrition and Dietetics* 117 (2):251–64. doi: 10.1016/j.jand.2016.09.021.

Mir, S. A., M. A. Shah, H. R. Naik, and I. A. Zargar. 2016. Influence of hydrocolloids on dough handling and technological properties of gluten-free breads. *Trends in Food Science & Technology* 51:49–57. doi: 10.1016/j.tifs.2016.03.005.

Mofrad, M. D., H. Mozaffari, S. M. Mousavi, A. Sheikhi, and A. Milajerdi. 2020. The effects of psyllium supplementation on body weight, body mass index and waist circumference in adults: A systematic review and dose-response meta-analysis of randomized controlled trials. *Critical Reviews in Food Science and Nutrition* 60 (5): 859–72. doi: 10.1080/10408398.2018.1553140.

Munari, A. C. F., W. B. Pinto, C. R. A. Andraca, and M. Casarrubias. 1998. Lowering glycaemic index of food by acarbose and *Plantago psyllium* mucilage. *Archives of Medical Research* 29:137–41.

Nami, Y., B. Haghshenas, and A. Y. Khosroushahi. 2017. Effect of psyllium and gum Arabic biopolymers on the survival rate and storage stability in yogurt of Enterococcus duransIW3 encapsulated in alginate. *Food Science & Nutrition* 5 (3):554–63. doi: 10.1002/fsn3.430.

Nie, S., S. W. Cui, and M. Xie. 2018. Psyllium polysaccharide. In *Bioactive polysaccharides*, 395–443. Cambridge: Elsevier. 10.1016/B978-0-12-809418-1.00008-3.

Niu, Y. G., Z. H. Xie, H. Zhang, Y. Sheng, and L. L. Yu. 2013. Effects of structural modifications on physicochemical and bile acid-binding properties of psyllium. *Journal of Agricultural and Food Chemistry* 61 (3):596–601.

Olson, B. H., S. M. Anderson, M. P. Becker, J. W. Anderson, D. B. Hunninghake, D. J. A. Jenkins, J. C. LaRosa, J. M. Rippe, D. C. K. Roberts, D. B. Stoy, et al. 1997. Psyllium-enriched cereals lower blood total cholesterol and LDL cholesterol, but not HDL cholesterol, in hypercholesterolemic adults: Results of a meta-analysis. *The Journal of Nutrition* 127 (10):1973–80., doi: 10.1093/jn/127.10.1973.

Pal, S., and S. Radavelli-Bagatini. 2012. Effects of psyllium on metabolic syndrome risk factors. *Obesity Reviews: An Official Journal of the International Association for the Study of Obesity* 13 (11):1034–47. doi: 10.1111/j.1467-789X.2012.01020.x.

Padayachee, A., L. Day, K. Howell, and M. J. Gidley. 2017. Complexity and health functionality of plant cell wall fibers from fruits and vegetables. *Critical Reviews in Food Science and Nutrition* 57 (1): 59–81. doi: 10.1080/10408398.2013.850652.

Pareyt, B., and J. A. Delcour. 2008. The role of wheat flour constituents, sugar, and fat in low moisture cereal based products: A review on sugar-snap cookies. *Critical Reviews in Food Science and Nutrition* 48 (9):824–39. doi: 10.1080/10408390701719223.

Park, H., P. A. Seib, and O. K. Chung. 1997. Fortifying bread with a mixture of wheat fibre and psyllium husk fibre plus three antioxidants. *Cereal Chemistry Journal* 74 (3):207–11. doi: 10.1094/CCHEM.1997.74.3.207.

Pejcz, E., R. Spychaj, A. Wojciechowicz-Budzisz, and Z. Gil. 2018. The effect of Plantago seeds and husk on wheat dough and bread functional properties. *Lwt* 96:371–7. doi: 10.1016/j.lwt.2018.05.060.

Peng, X. Y., and Y. Yao. 2017. Carbohydrates as fat replacers. *Annual Review of Food Science and Technology* 8:331–51. doi: 10.1146/annurev-food-030216-030034.

Peredo, A. G., C. I. Beristain, L. A. Pascual, E. Azuara, and M. Jimenez. 2016. The effect of prebiotics on the viability of encapsulated probiotic bacteria. *LwtFood Science and Technology* 73:191–6. doi: 10.1016/j.lwt.2016.06.021.

Peressini, D., A. Cavarape, M. A. Brennan, J. R. Gao, and C. S. Brennan. 2020. Viscoelastic properties of durum wheat doughs enriched with soluble dietary fibres in relation to pasta-making performance and glycaemic response of spaghetti. *Food Hydrocolloids* 102:105613. doi: 10.1016/j.foodhyd.2019.105613.

Ramkumar, D., and S. S. C. Rao. 2005. Efficacy and safety of traditional medical therapies for chronic constipation: Systematic review. *The American Journal of Gastroenterology* 100 (4):936–71. doi: 10.1111/j.1572-0241.2005.40925.x.

Ray, A., P. K. Prakash, A. J. Lakshmi, and I. Dasappa. 2018. Modulation of carbohydrate digestibility of north Indian parotta using protein and dietary fibre based functional ingredients. *Starch - Stärke* 70 (9-10):1700269. doi: 10.1002/star.201700269.

Raymundo, A., P. Fradinho, and M. C. Nunes. 2014. Effect of Psyllium fibre content on the textural and rheological characteristics of biscuit and biscuit dough. *Bioactive Carbohydrates and Dietary Fibre* 3 (2): 96–105. doi: 10.1016/j.bcdf.2014.03.001.

Ren, Y., B. R. Linter, and T. J. Foster. 2020. Cellulose fibrillation and interaction with psyllium seed husk heteroxylan. *Food Hydrocolloids* 104:105725. doi: 10.1016/j.foodhyd.2020.105725.

Rigaud, D., F. Paycha, A. Meulemans, M. Merrouche, and M. Mignon. 1998. Effect of psyllium on gastric emptying, hunger feeling and food intake in normal volunteers: A double blind study. *European Journal of Clinical Nutrition* 52 (4):239–45. doi: 10.1038/sj.ejcn.1600518.

Román, L., M. Belorio, and M. Gómez. 2019. Gluten-free breads: The gap between research and commercial reality. In *Comprehensive reviews in food science and food safety*, 18:1–13.

Rosell, C. M., J. A. Rojas, and C. B. de Barber. 2001. Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids* 15 (1):75–81. doi: 10.1016/S0268-005X(00)00054-0.

Sabanis, D., and C. Tzia. 2011. Effect of hydrocolloids on selected properties of gluten-free dough and bread. *Food Science and Technology International = Ciencia y Tecnologia de Los Alimentos Internacional* 17 (4):279–91. doi: 10.1177/1082013210382350.

Saha, D., and S. Bhattacharya. 2010. Hydrocolloids as thickening and gelling agents in food: A critical review. *Journal of Food Science and Technology* 47 (6):587–97. doi: 10.1007/s13197-010-0162-6.

Sarkar, S., and R. K. Lal. 2018. Genetic architecture of some agronomic traits as deciphered from diallel cross analysis of Plantago ovata Forsk. *Journal of Applied Research on Medicinal and Aromatic Plants* 9:55–61. doi: 10.1016/j.jarmap.2018.02.002.

Sciarini, L. S., P. D. Ribotta, A. E. Leon, and G. T. Perez. 2010. Effect of hydrocolloids on gluten-free batter properties and bread quality. *International Journal of Food Science & Technology* 45 (11):2306–12. doi: 10.1111/j.1365-2621.2010.02407.x.

Gupta, S., C. Milind, T. Jeyarani, and J. Rajiv. 2015. Rheology, fatty acid profile and quality characteristics of nutrient enriched pizza base. *Journal of Food Science and Technology-Mysore* 52:2926–33. doi: 10.1007/s13197-014-1338-2.

Sim, S. Y., A. A. N. Aziah, and L. H. Cheng. 2015. Quality and functionality of Chinese steamed bread and dough added with selected non-starch polysaccharides. *Journal of Food Science and Technology* 52 (1):303–10. doi: 10.1007/s13197-013-0967-1.

Singh, B. 2007. Psyllium as therapeutic and drug delivery agent. *International Journal of Pharmaceutics* 334 (1-2):1–14. doi: 10.1016/j.ijpharm.2007.01.028.

Slavin, J. 2013. Fiber and prebiotics: Mechanisms and health benefits. *Nutrients* 5 (4):1417–35. doi: 10.3390/nu5041417.

Syrbe, A., W. J. Bauer, and N. Klostermeyer. 1998. Polymer science concepts in dairy systems - An overview of milk protein and food hydrocolloid interaction. *International Dairy Journal* 8 (3):179–93. doi: 10.1016/S0958-6946(98)00041-7.

Su, H. P., C. P. Lien, T. A. Lee, and J. H. Ho. 2010. Development of low-fat mayonnaise containing polysaccharide gums as functional ingredients. *Journal of the Science of Food and Agriculture* 90 (5):806–12. doi: 10.1002/jsfa.3888.

Sukhija, S., S. Singh, and C. S. Riar. 2016. Analysing the effect of whey protein concentrate and psyllium husk on various characteristics of biodegradable film from lotus (Nelumbo nucifera) rhizome starch. *Food Hydrocolloids* 60:128–37. doi: 10.1016/j.foodhyd.2016.03.023.

Tubili, C., U. Di Folco, O. M. S. Hassan, S. Agrigento, G. Carta, M. M. Pandolfo, and M. R. Nardone. 2016. Fibre enriched protein-free pasta and bread: Is it a useful tool in chronic kidney disease in type 2 diabetes?. *Mediterranean Journal of Nutrition and Metabolism* 9 (2):95–9. doi: 10.3233/MNM-160062.

Tuncil, Y. E., R. D. Thakkar, S. Arioglu-Tuncil, B. R. Hamaker, and S. R. Lindemann. 2020. Subtle variations in dietary-fiber fine structure differentially influence the composition and metabolic function of gut microbiota. *mSphere* 5 (3):e00180. doi: 10.1128/mSphere.00180-20.

Warnberg, J., A. Marcos, G. Bueno, and L. A. Moreno. 2009. Functional benefits of psyllium fibre supplementation. *Current Topics in Nutraceutical Research* 7:55–63.

Wei, Z-h, H. Wang, X-y Chen, B-s Wang, Z-x Rong, B-s Wang, B-h Su, and H-z Chen. 2009. Time- and dose-dependent effect of psyllium on serum lipids in mild-to-moderate hypercholesterolemia: A meta-analysis of controlled clinical trials. *European Journal of Clinical Nutrition* 63 (7):821–7. doi: 10.1038/ejcn.2008.49.

Wolever, T. M. S., V. Vuksan, H. Eshuis, P. Spadafora, R. D. Peterson, E. S. M. Chao, M. L. Storey, and D. J. A. Jenkins. 1991. Effect of method of administration of psyllium on glycemic response and carbohydrate digestibility. *Journal of the American College of Nutrition* 10 (4):364–71. doi: 10.1080/07315724.1991.10718164.

Xing, L. C., D. Santhi, A. G. Shar, M. Saeed, M. A. Arain, A. H. Shar, Z. A. Bhutto, M. U. Kakar, R. Manzoor, M. E. A. El-Hack, et al. 2017. Psyllium husk (*Plantago ovata*) as a potent hypocholesterolemic agent in animal, human and poultry. *International Journal of Pharmacology* 13 (7):690–7. doi: 10.3923/ijp.2017.690.697.

Yadav, N., V. Sharma, S. Kapila, R. K. Malik, and S. Arora. 2016. Hypocholesterolaemic and prebiotic effect of partially hydrolysed psyllium husk supplemented yoghurt. *Journal of Functional Foods* 24:351–8. doi: 10.1016/j.jff.2016.04.028.

Yin, J. Y., H. H. Chen, H. X. Lin, M. Y. Xie, and S. P. Nie. 2016. Structural features of alkaline extracted polysaccharide from the seeds of Plantago asiatica L. and its rheological properties. *Molecules* 21 (9):1181. doi: 10.3390/molecules21091181.

Yin, J. Y., S. P. Nie, Q. B. Guo, Q. Wang, S. W. Cui, and M. Y. Xie. 2015. Effect of calcium on solution and conformational characteristics of polysaccharide from seeds of *Plantago asiatica* L. *Carbohydrate Polymers* 124:331–6. doi: 10.1016/j.carbpol.2015.02.017.

Yin, J. Y., H. X. Lin, J. Li, Y. X. Wang, S. W. Cui, S. P. Nie, and M. Y. Xie. 2012. Structural characterization of a highly branched polysaccharide from the seeds of *Plantago asiatica* L. *Carbohydrate Polymers* 87 (4):2416–24. doi: 10.1016/j.carbpol.2011.11.009.

Yin, J. Y., S. P. Nie, J. Li, C. Li, S. W. Cui, and M. Y. Xie. 2012. Mechanism of interactions between calcium and viscous polysaccharide from the seeds of Plantago asiatica L. *Journal of Agricultural and Food Chemistry* 60 (32):7981–7. doi: 10.1021/jf302052t.

Yokoyama, S., K. Hori, K. I. Tamine, S. Fujiwara, M. Inoue, Y. Maeda, T. Funami, S. Ishihara, and T. Ono. 2014. Tongue pressure modulation for initial gel consistency in a different oral strategy. *PLOS One* 9 (3):e91920. doi: 10.1371/journal.pone.0091920.

Yu, L. L., and J. Perret. 2003a. Effects of solid-state enzyme treatments on the water-absorbing and gelling properties of psyllium. *Food Science and Technology* 36:203–8.

Yu, L. (L.)., and J. Perret. 2003b. Effects of xylanase treatments on gelling and water-uptaking properties of psyllium. *Journal of Agricultural and Food Chemistry* 51 (2):492–5. doi: 10.1021/jf020644l.

Yu, L. L., J. Perret, T. Parker, and K. G. D. Allen. 2003. Enzymatic modification to improve the water-absorbing and gelling properties of psyllium. *Food Chemistry* 82 (2):243–8. doi: 10.1016/S0308-8146(02)00520-4.

Yu, L., G. E. Yakubov, W. Zeng, X. H. Xing, J. Stenson, V. Bulone, and J. R. Stokes. 2017. Multi-layer mucilage of *Plantago ovata* seeds: Rheological differences arise from variations in arabinoxylan side chains. *Carbohydrate Polymers* 165:132–41. doi: 10.1016/j.carbpol.2017.02.038.

Zandonadi, R. P., R. B. Assunção-Botelho, and W. M. Coelho-Araújo. 2009. Psyllium as a substitute for gluten in bread. *Journal of the American Dietetic Association* 109 (10):1781–4. doi: 10.1016/j.jada.2009.07.032.

Zhang, J., C. Wen, H. Zhang, and Y. Duan. 2019. Review of isolation, structural properties, chain conformation, and bioactivities of psyllium polysaccharides. *International Journal of Biological Macromolecules* 139:409–20. doi: 10.1016/j.ijbiomac.2019.08.014.

Zbikowska, A., M. Kowalska, and J. Pieniowska. 2018. Assessment of shortcrust biscuits with reduced fat content of microcrystalline cellulose and psyllium as fat replacements. *Journal of Food Processing and Preservation* 42 (8):e13675. doi: 10.1111/jfpp.13675.

Ziemichód, A., M. Wójcik, and R. Różyło. 2019. Seeds of *Plantago psyllium* and *Plantago ovata*: Mineral composition, grinding, and use for gluten-free bread as substitutes for hydrocolloids. *Journal of Food Process Engineering* 42 (1):e12931. doi: 10.1111/jfpe.12931.