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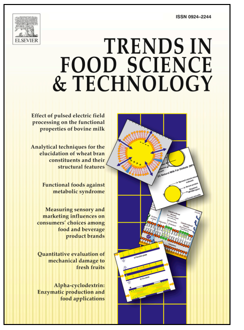

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Abstract

Background

Fiber intake has been associated with a lower risk of developing various chronic diseases such as metabolic diseases (e.g. obesity, diabetes, dyslipidemia). In this line, psyllium presents a high content of soluble fiber, associated with health benefits.

Scope and approach

The aim of this review is to evaluate the scientific evidence of psyllium health benefits. The nutritional properties of psyllium are presented, as well as its various applications in food products. The main functional benefits of psyllium are presented in topics, as follows: the effect on cholesterol control, on type 2 diabetes, and on obesity and satiety.

Key findings and conclusions

Products containing psyllium can be an effective alternative to improve the functionality and produce healthy foods. The addition of psyllium to a food product (e.g. bakery goods, dairy, meat and gluten-free products). Can provide the health claim for a fiber-containing product, which is an important advantage in the market. In addition, it may allow consumers to ingest adequate amounts of fiber without increasing calorie intake, as well as contributing to other health benefits such as cholesterol control, glycemic control, satiety, among others. Psyllium can be easily added to food formulations and does not change the flavor perception of the product. Thus, the food industry may play an important role in the prevention of chronic non-communicable diseases when using psyllium in food products.

Keywords: arabinoxylan, satiety, soluble fiber, cholesterol, type 2 diabetes, gluten-free, psyllium

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1. Introduction

The interesting on natural components of plants is increasing due to their association with health benefits (Singh, 2007; Ribeiro-Santos et al., 2015; 2017).

Psyllium is a plant with high content in water-soluble fiber, which exerts a number of positive effects on health, possess pharmaceutical properties and desirable nutritional effects (Alabaster, Tang & Frost, 1993).

Psyllium is the common name found in the seed of an annual plant of the Plantago genus, which has around 200 different species. Scientifically known as *Plantago ovata* Forsk, the most important and known species with a wide variety of uses. It is also called Isabgol, meaning ''horse ear'' in Indian, which describes the shape of the seed (Dhar , Kaul , Sareen, Kou,2005; Masood & Miraftab, 2010).

Psyllium is popularly used in the traditional Indian medicine system (Ayurveda) for prevention of skin irritations, hemorrhoids, constipation as well as diarrhea. Its consumption in Europe has increased in recent years and now is also widespread in the USA (Fradinho, Nunes & Raymundo, 2015). The world commercial market is dominated by India, in the production and export of psyllium. The crop is mainly cultivated in Gujarat and Rajasthan that are the major producer states of psyllium in India. Regarding further processing and manufacturing of husk, Gujarat is the leading state contributing 35% of world production of psyllium (Verma & Mogra, 2013).

From the seed coat of psyllium (*P. ovata*), a mucilage is obtained, by mechanical milling, grinding of the outer layer of the seed. Mucilage describes a group of clear, colourless, gelling agents derived from plants (Verma & Mogra, 2013). Psyllium mucilage has a long history as a nutritional supplement due to be considered as a good source for soluble and insoluble fiber being reported as a medicinally active gel forming natural polysaccharide (Singh, 2007). It is a gel forming mucilage known for its laxative effect due to its high-water holding capacity, which is approximately 80 times of its weight (Yadav , Sharma , Kapila , Malik &Arora 2016).

Psyllium has been widely investigated for its potential health benefits and its applications in food and pharmaceutical industries (Singh, 2007; Yu, Lutterodt & Cheng, 2009). Psyllium is well recognized for the treatment of constipation, irritable bowel syndrome symptoms, abdominal pain, cancer prevention, diarrhea, inflammatory bowel disease-ulcerative colitis, obesity, diabetes and hypercholesterolemia. Besides it, contributes for satiety, hypocholesterolaemic and prebiotic effects (Alabaster et al., 1993; Bijkerk, Muris, Knottnerus, Hoes & De Wi, 2004; Singh 2007; Yu, Lutterodt & Cheng, 2009; Galisteo, Morón, Rivera, Romero, Anguera & Zarzuelo2010; Bernaud & Rodrigues, 2013; Yadav et al., 2016; (Brum, Gibb, Peters, & Mattes, 2016). In addition to its beneficial health effects, psyllium seed husk which is a well-known source for the production of psyllium hydrocolloid, has also functional function in food due to its strong hydrophilic and gelling properties, stabilizing suspending and emulsifying power. gums are of high molecular weight and can be expected to be good viscosity enhancers (Guo, Cui, Wang, & Christopher Young, 2008; Yu, Lutterodt & Cheng, 2009; Bahmani, Mirhosseini, Fasihzadeh, Karimian & Rafieian-Kopaei 2016). In supplements and development of food products, staple foods enriched with psyllium fiber such as biscuits and yogurt has been described and in producing low calorie and less fat food and as substitute for gluten (Zandonadi, Botelho & Araújo, 2009; Fradinho, Nunes & Raymundo, 2015; Ladjevardi, Gharibzahedi & Mousavi, 2015).

Psyllium is also widely applied in cosmetics (for providing hair and skin care products), textiles, paper-making, printing inks, waxes and army industries (water proofing explosives) (Bahmani et al 2016).

This review aims to evaluate the scientific evidence of the main functional health benefits of psyllium (*Plantago ovata*) and also discusses its biological proprieties and components. The use of this fiber by the food industry and as a medicinal agent is also addressed.

2. Brief history

The genus *Plantago* is one of the largest of the three genera of Plantaginaceae family, comprising more than 250 species worldwide (Gupta, 1991; Panda, 2002). *Plantago* species are mainly distributed in the temperate regions (between 26-36ºN, latitude) and just few are found in the tropics (Board, 2003; Haddadian, Haddadian & Zahmatkash, 2014). According to van der Aart and Vulto (1992), the rosette-forming *Plantago* species belong to the subgenus *Plantago* and the recent stem-forming *Plantago* species belong to the subgenus *Psyllium.*

The seeds of *Plantago* have been used for centuries in the indigenous medicine and they are produced by several European countries, Paskistan and India. Only two species of the genus *Plantago* (*P. ovata* Forsk. *and P. psyllium)* are cultivated for their seed husk in demand for cosmetic and pharmaceutical industries (Gupta, 1991; Panda, 2002; Board, 2003). Seeds are emollient, and promote bowel movements and can alleviate the inflammation of the mucous membrane of the gastrointestinal tract (Gupta, 1991). Moreover, *Plantago* can be used to prepare ice cream (Dhar et al., 2005). *P. ovata* produces a higher yield than *P. psyllium* and it presents a larger seed size. Besides it is better in terms of colorless and swelling properties, being known as French psyllium (Board, 2003). *Plantago* is cultivated in arid parts of Western India (Gupta, 1991) and India dominates the production and exportation of psyllium. The seed husk can absorb and retain water, therefore it is commonly used to treat constipation, chronic dysentery and related disorders. Both seeds and seed husks are imported annually by countries of Western Europe and USA (Gupta, 1991).

The scientific name of psyllium is *Plantago ovata Forsk. (Syn. P. Ispghagula Roxb.)* and it is known for commercial purposes as Indian *plantago*, isabgol or white or blonde psyllium (Gupta, 1991; Panda, 2002). The common names of *P. ovata* include Ashwagolam Babka, Isphghol or Spangur, in India; Barhanj in Poland, Ch-chientzu in China; Barhanj, Bidr qtn, Blond psyllium and Buzar qatona in Arabic countries, Obeko in Japan, Psillo indiano in Germany and Spogel in Iran.

The name *Plantago* derives from Latin and it means sole of the foot, which refers to the psyllium leaf. In Persian the common name is isapghul which corresponds to two Persian words “isap” + “ghol” which means horse car in reference to boat shaped seeds (Gupta, 1991; Panda, 2002; Board, 2003).

3. Distribution and cultivation and botanical description

Plantago is especially distributed in India, Iran, Pakistan, Bangladesh, as shown in detail in **Figure 1**. The geographical location of this region provides an ideal environment for growing this plant. It is believed that psyllium was introduced in undivided India during the Mughal rule (Board, 2003). As the demand for seed increased, cultivation started and was initially confined to Lahore and Multan (presently Pakistan), spreading to Bengal (Board, 2003) afterward. Currently, India is the largest producer and the main supplier of *Plantago* seeds and husks to the world market, about 90% of the production is exported. Economic analysis shows that the US is the main importer of *Plantago* seeds and husks, consuming 8,000 tons annually. *Plantago* ranks sixth in the economic trade of medicinal plants (Brasil, 2014; Khaliq, Tita, Antofie, & Sava, 2015; Shahriari, Heidari, & Dadkhodaie, 2018).

P. ovata generally grows in semi-arid or arid climates in the cold season in order to be possible to find some irrigation (Bannayan et al., 2008). The crop is not exigent in terms of soil fertility, so it can develop in a poor fertility sandy-loam to loamy soil (Gupta, 1991).

P. ovata is a short-stemmed or stemless annual herb that grows to 30-45 cm tall (Dhar et al., 2005; Gupta, 1991). Leaves can reach 7.5 to 25 cm long and they are narrow (5 to 12.5 mm), linear, linear lanceolate or filiform, three-nerved and coated with fine and soft hairs (Gupta, 1991).

Roots present a well-developed taproot with few fibrous secondary roots. Flowering shoots arise from the base of the plant and flowers appear approximately affect 60 days after planting and they are white, 12.5 to 37.5 mm in length and with bracts 4 mm long and broad. Moreover, when psyllium is ripened when flower spikes turn reddish brown. At this stage, upper leaves turn yellow and lower leaves dry up. Spikes have 45 to 69 flowers. Flowers are tetramerous, anemophilous and protogynous (Gupta, 1991).

The fruit is a small ellipsoidal capsule (about 8 mm long) that opens at maturity. About 1000 seeds weight 1.5 g (Panda, 2002). It contains hard, boat-shaped, rosy white or rosy brown seeds, up to 8m (long) x 1 mm (broad). The surface of the seeds is glossy and shining. There is an oval spot in the center of convex surface and in the concave surface there is a deep furrow with a hilum, which seems like a red spot in the center (Gupta, 1991).

Seed husk is separated from seed during milling and it is an odourless, tasteless, translucent, rosy-white mucilaginous membrane, corresponding to about 30% of seed weight (Gupta, 1991).

Different breeding methods have been used for the improvement of this important medicinal plant (*P. ovata*), including selection, induced mutations, hybridization, polyploidy and tissue culture, but the only one with good results was selection, which originated isolation of a few varieties (Dhar et al., 2005). The Gujarat Isabgol-1 and Gujarat Isabgol-2 are two varieties of *P. ovata* cultivated in India with high yield of seed husk (Gupta, 1991).

4. Nutritional Composition and bioactive components

Table 1 shows the proximate and monosaccharides content of psyllium. Minerals content is exhibited in **Table 2**.

The largest part of psyllium husk seeds consisted of carbohydrates. It was identified a variety of monosaccharides, being, the most abundant xylose and arabinose. As reported in the European Medicines Agency (2013), psyllium husk consists of 85% water-soluble fibre. The polysaccharidic fraction comprises: 65% D-xylose, 20% L-arabinose, 6% rhamnose and 9% D-galacturonic acid. Psyllium husk contains a fraction of more than 60% arabinoxylan (AX), this fraction is a hemicellulose having a xylose linked with arabinose (Guo, Cui, Wang, & Christopher Young, 2008; Michlmayr et al., 2013). The main source of AX is psyllium (Guo et al., 2008; Saghir, Iqbal, Hussain, Koschella, & Heinze, 2008). Additionally, K, Na and P are the minerals present in higher quantities. Bukhsh, Malik and Ahmad (2007) reported that seeds of *P. ovate* contain significantly higher amount of fiber as compared to the leaves, while the concentration of proteins and total carbohydrates in leaves are significantly higher as compared to seeds.

Phytochemicals are bioactive compounds produced by plants that can protect the human body from many diseases (Yi, Cao, Cao, & Xiao, 2019).

Kotwal, Kaul, & Dhar (2019) verified the total phenolic content of leaf and husk extracts of *P. ovata* seeds and the results showed an efficient elimination of free radicals. According to the authors, this property should be explored as a supplement to health care.

According to Talukder et al. (2016), *P. ovata* seeds and husks are rich in bioactive compounds while the most abundant are fatty acids, amino acids, polyphenols, and flavonoids. In the studies of Manish K. Patel et al. (2016), linoleic acid, oleic acid, and palmitic acid are among the fatty acids found in *P. ovata* husks. The seeds, leaves, and psyllium husks have phenolic compounds and presented antioxidant activity. In the same study, the seeds and husk extracts contained terpene, including saponins.

For Manish Kumar Patel et al. (2019), the polysaccharides found in the seed and psyllium husk should be further explored for developing formulations in the nutraceutical industry due to their antioxidant capacity and anticancer agent.

5. Main functional and medicinal benefits of Psyllium

Psyllium can be classified as a functional fiber once it is a non-digestible carbohydrate comprised of the major monosaccharides arabinose and xylose forming the active fraction of arabinoxylans, which is related to the formation of the viscous gel. Viscous gel-forming fibers have physiological health benefits (Institute of Medicine, 2005; McRorie; Mckeown, 2017; Marlett & Fischer, 2001). When psyllium is mixed with water, there is the formation of a gel-like mucilage, and the resulting viscosity may interfere with the absorption of fat and cholesterol which can lead to a reduction of the blood cholesterol concentrations (Institute of Medicine, 2005).

Lu, Walker, Muir, Mascara, & O'Dea (2000) performed consistent studies about the effect of arabinoxylan on glycemic control and insulin action in patients with type 2 diabetes. According to the authors, although the mode of action of arabinoxylans in improving glucose tolerance is unknown, it is probably due to the high viscosity of the fiber within the small intestine that can interfere with the absorption of glucose. Recent studies have reported that psyllium contributes to glycemic control because the gel can protect the macronutrients and slow digestion (McRorie, 2015; Giacco, Costabile, & Riccardi, 2016). The increase in the viscosity of gastric fluid leads to a decrease in the interactions between the digestive enzymes and nutrients. The nutrient absorption occurs slowly and gradually throughout the passage through the small intestine, concentrating more in the region of the distal ileum (McRorie, 2015). With absorption into the distal ileum region, cells are stimulated to release Glucagon-like peptide-1 (GLP-1) into the bloodstream, which increases the growth of pancreatic beta cells that produce insulin, which is responsible for the control of glucose levels in the human body (Ellingsgaard et al., 2011).

Another benefit of delivery of nutrients to the distal ileum is the stimulation of the ileal brake mechanism, which causes a delay in gastric emptying and intestinal transit, reducing hunger and food intake (Alleleyn, Van Avesaat, Troost, & Masclee, 2016).

Pal, Khossousi, Binns, Dhaliwal, & Ellis (2011) carried out a 72-week study, in which one group consumed 12 grams of psyllium diluted in 250 mL water, 10 minutes before meals (breakfast, lunch, and dinner) and another group did not consume psyllium. The psyllium-treated group showed a reduction in glucose and cholesterol levels, demonstrating that psyllium is an excellent alternative for people with overweight or obese, who present risk factors for metabolic syndrome, being susceptible to heart disease and type 2 diabetes. Soluble fibers are good alternatives for those patients due to the formation of a viscous gel, which increases satiety and reduces hunger. The feeling of satiety leads to the cessation of food intake during the interval before the next meal (Marciani et al., 2000). According to Lambeau and McRorie (2017), soluble fibers are more effective alternatives when compared to the insoluble fibers for weight loss, once insoluble fibers release fatty acids during fermentation that are absorbed, leading to absorption of calories.

Unlike nutrients that can be absorbed throughout the entire transit in the small intestine, bile recycling occurs only in the region of the distal ileum. Bile acids are involved in the digestion of lipids occurring in the small intestine (Lambeau & McRorie, 2017). The viscosity of the gel formed by psyllium hinders the recovery of bile acids in the region of the distal ileum, which is lost by feces, leading to an increase in LDL (Low-Density Lipoproteins) cholesterol in the blood. According to El Khoury, Cuda, Luhovyy & Anderson (2012), the reduction of blood cholesterol levels caused by the consumption of soluble fibers may be due to excretion of bile acids by feces.

The inclusion of psyllium in the diet may be a simple and effective method to regulate blood lipids, insulin, and glucose rates in overweight or obese people, leading to a reduction in the risk of metabolic syndrome, cardiovascular disease, and type 2 diabetes. In addition, psyllium is poorly fermented when compared to other fibers, causes less flatulence, less abdominal bloating, and is easily tolerated by consumers and marketed worldwide (Pal, Ho, Gahler, & Wood, 2017; Pal, Khossousi, Binns, Dhaliwal, & Ellis, 2011).

The psyllium husk can be used to reduce the symptoms of gastrointestinal disorders in patients with Parkinson's disease. According to the study by Fernandez-Martinez et al. (2014), *P. ovata* may be a good alternative to help solve constipation problems in patients with Parkinson's disease. The volunteers took 3.5 g of *P. ovata* in 200 mL of water prior to administration of oral medication (levodopa/carbidopa). The study showed that fiber contributed to maintaining steady concentrations of the drug while the fiber did not retain part of the administered dose, which is a very important outcome for patients with Parkinson's.

Pawar & Varkhade (2014) investigated using the polysaccharide derived from *P. ovata* as a pill coat in the development of rapid dissolution tablets to treat hypertension. The formulations containing the polysaccharide disintegrated rapidly and completely due to their swelling property. The polysaccharide of the *P. ovata* used as a pill coat is inexpensive, non-toxic, and easy to manufacture compared to the synthetic materials.

Prepared tablets offered benefits in terms of patient compliance, rapid onset of action, increased bioavailability, few side effects, and good stability.

In another study, the protective effect of the aqueous extract of *Plantago ovata* was verified against peptic ulcer induced by a gastric ulcer in rats. The aqueous seed extract of *Plantago ovata* has been shown to prevent gastrointestinal lesions and damage to the liver. This may be due to the solubility and viscosity of the fiber (Majid & Zare-mohazabieh, 2018).

Several studies have shown the *P. ovata* benefits on health. Many remedies are already marketed based on these benefits. In Brazil, Anvisa authorized an effervescent powder for oral use to treat intestinal constipation (Anvisa Registration Nº: 1063902050031, BRASIL, 2019).

In addition to the effervescent powder, psyllium capsule and liquid can also be found. In the U.S. National Library of Medicine, revised in 2015, it is possible to check various drug-producing brands using psyllium alone or in combination.

5.1 Effect on cholesterol control

According to Food and Drug Administration (FDA) the consumption of 7g or more of psyllium per day, associated with a diet with low amounts of saturated fat and cholesterol, can reduce the risk of coronary heart disease (FDA,2012),. Total cholesterol and elevated LDL levels are associated with an increased risk of developing coronary heart disease. According to The Official Journal of Federative Republic of Brazil (Diário Oficial da República Federativa do Brasil) (Brasil, 1999), a food product containing 3g psyllium in a daily portion may present the claim of functional property on the label, informing that its consumption, when associated with a balanced diet and healthy life habits, helps in reducing the fat absorption. According to the European Commission, a product may put on its label "Source of fiber" when the product contains at least 3 g of fiber per 100 g of product and for the claim of "High in fiber" 6 g of fiber per 100 g of product (EC, 2006).

A study carried out with 28 men diagnosed with coronary heart disease showed that the consumption of 10.5 g psyllium per day reduced patients' waist circumference, with a reduction of 6.7% in triglyceride levels, demonstrating that psyllium can be used as adjuvant treatment in patients with moderate hypertriglyceridemia (Solà et al., 2007).

Wei et al. (2008) analyzed 21 studies between 1988 and 2000 and found the relationship between the consumption of psyllium and the reduction of cholesterol and

LDL levels. In all studies, there were significant reductions in cholesterol and LDL levels, despite the different daily dosages of psyllium and different duration of treatment. According to the authors, although the higher psyllium intake is not associated with the increase in the reduction of total cholesterol and LDL, its prolonged consumption can lead to the reduction of total cholesterol and LDL levels. **Table 3** presents some studies showing that the psyllium intake reduced the cholesterol and LDL levels.

Anderson et al. (2000) investigated 8 studies on the effects of psyllium consumption in people with mild to moderate hypercholesterolemia. In all studies, the dosage and duration of treatment were the same, and psyllium significantly reduced total cholesterol and LDL cholesterol levels, as shown in **Table 3**.

Ganji and Kuo (2008) incorporated psyllium into cookies and offered to a group of 8 pre and 11 postmenopausal women. Each cookie contained 5g psyllium and the orientation was to consume 3 cookies a day along with meals. The authors identified significant differences between pre and postmenopausal women, with a reduction in total cholesterol rates in postmenopausal women, probably due to differences in hormone rates between the patients. Although reductions in total cholesterol and LDL cholesterol levels were expected, it was not observed probably due to the amount of fat of the cookie formulation, which may have reduced the hypocholesterolemic effect of psyllium. The form of consumption of psyllium may interfere with the results, because a recent study on the consumption of 5g psyllium 3 times a day, at 5 to 10 minutes before meals (breakfast, lunch, and dinner), for 12 months, showed a significant reduction of total cholesterol and LDL cholesterol levels from the third month. The protocol consisted of the intake of the product with 250 mL water, followed by ingesting another 250 mL water (Pal et al., 2017).

In a study with patients diagnosed with moderate hypercholesterolemia, the consumption of psyllium led to a reduction in triglyceride levels of 21.6% when compared to placebo, besides contributing to significant reductions of total and LDL cholesterol. The authors recommended the daily intake of psyllium for people with risk factors for cardiovascular diseases, such as metabolic syndrome, especially in the event of any drug intolerance (Solá et al., 2010).

The consumption of psyllium led to a reduction of the LDL cholesterol levels in male adolescents (aged 15 and 16 years) and showed an improvement in the body fat distribution, with a decrease in adiposity (De Bock et al., 2012). Another study with t and children (aged 6 to 19 years) presented a reduction of LDL cholesterol levels, with no consumers' rejection for the aroma, flavor, appearance or texture, allowing the effective incorporation of psyllium into the diet. The inclusion of psyllium in the diet may be useful for children and adolescents who cannot use the medication in the treatment of hypercholesterolemia (Ribas, Cunha, Sichieri, & Carlos, 2017).

Lambeau and McRorie (2017) performed 24 well-controlled clinical studies with more than 1500 individuals, with doses ranging from 6 to 15 g psyllium per day, confirming the effectiveness of psyllium in reducing the total cholesterol levels by 2 to 20%, with a 6 to 24% reduction of LDL cholesterol.

5.2 Effect on type 2 diabetes

Diabetes is a chronic disease characterized by high blood glucose levels that result from the body's inability to produce insulin (Triplitt, Solis-Herrera, Cersosimo, Abdul-Ghani, & Defronzo, 2015). According to the International Diabetes Foundation (IDF), diabetes kills one person every 6 seconds, and the estimation is that more than 415 million people will be diagnosed with diabetes by 2040 (Pugazhenthi, Qin, & Reddy, 2017).

The consumption of dietary fiber may reduce the risk of coronary heart disease and diabetes, and a daily intake greater than 26 g may reduce the risk of developing type 2 diabetes mellitus by up to 18% (Kaczmarczyk, Miller, & Freund, 2012; The Interact Consortium, 2015).

Some studies have shown that the daily consumption of psyllium has reduced blood glucose levels (Abutair, Naser, & Hamed, 2016; Anderson et al., 2009; Gibb, Jr, Russell, Hasselblad, & Alessio, 2015).

Anderson, Allgood, Turner, Oeltgen and Daggy (1999) conducted an 8-weeks study with 56 male patients with type 2 diabetes mellitus. The patients were instructed to dilute 5 g psyllium in 240 mL water and consume it before coffee and dinner, totaling 10 g psyllium per day. The results showed a reduction in blood glucose and lipid levels. For those with diabetes, it is important to maintain normal blood lipid concentrations with reduced fasting and postprandial glycemic levels.

The findings of Cicero, Derosa, Bove, Imola, Borghi, and Gaddi et al. (2010) corroborate with the information on the efficacy of psyllium before meals. The authors studied the consumption of 3.5 g psyllium 20 minutes, before the two main meals, for 6 months, and found that psyllium is effective for individuals who need to reduce cardiovascular risk factors, such as hypercholesterolemia, hypertriglyceridemia, hyperglycemia, and hypertension.

Gibb et al. (2015) analyzed 35 studies from 1981 to 2011 on the effect of psyllium on glycemic control in patients with type 2 diabetes mellitus and reported an effective decrease in fasting and postprandial blood glucose concentrations when psyllium was administered before meals.

Similarly, Feinglos, Gibb, Ramsey, Surwit, & McRorie (2013) investigated the effects of psyllium intake on glycemic regulation in 90 patients diagnosed with type 2 diabetes mellitus, age from 36 to 80 years, for 12 weeks. The patients consumed psyllium twice daily, before breakfast and dinner. One group consumed 6.8 g and the other group consumed 13.6 g per day. The results showed that both dosages were effective in reducing glycemic levels when compared to the placebo, for both fasting glycemic levels and HbA1c (glycated hemoglobin) levels.

A similar study was carried out by Abutair et al. (2016) with 40 type 2 diabetes mellitus patients, aged 35 years, for 8 weeks. The participants were instructed to consume 3.5g psyllium diluted in 100 mL water, 15 minutes before lunch and dinner, totaling 7 g psyllium per day. The result showed a reduction in glycemic rates in both fasting glycemia and HbA1c rates. The low HbA1c level indicated that glycemia was well controlled over the past few months. The soluble fiber of psyllium deserves attention as it is a potential supplement for use in the control of type 2 diabetes, with positive results in a short period of time.

Ricklefs-Johnson, Johnston, & Sweazea (2017) studied the effect of the psyllium consumption on weight reduction and improvement of glycemic and lipid regulation when compared to flaxseed consumption. For the study, 19 adult patients diagnosed with type 2 diabetes mellitus were divided into two groups: one group consumed 9 g psyllium per day and the other group 28 g flaxseed per day for 8 weeks (28 g flaxseed contains the same amount of soluble fiber than in 9 g psyllium). The participants were instructed to distribute the fiber dosage throughout the day. Both groups obtained a significant reduction in waist circumference without reducing body weight, however, with no significant reductions in glycemic and lipid levels, probably due to the sample size and the lower dosage administered.

When comparing the studies by Ricklefs-Johnson et al.(2017) and Anderson et al. (1999), the sample size was smaller than the other studies, with no differences for the duration and dosage (Abutair et al., 2016; Feinglos et al., 2013). Ricklefs-Johnson et al.

(2017) did not report how the fibers were consumed by the participants, which may have affected the results. The authors instructed to distribute the amount of fiber throughout the day, while in other studies the fiber intake was divided into two doses before meals, while Anderson et al. (1999) and Abutair et al. (2016) recommended the dilution of psyllium in water.

5.3 Effect on obesity and satiety

Obesity and overweight are associated with increased adipose tissue mass and predispose to insulin resistance, which is associated with diabetes (Farag & Gaballa, 2011; Maury & Brichard, 2010). Psyllium has presented consistent results in the search for natural products that can contribute to weight loss and increased (Brum, Gibb, Peters, & Mattes, 2016; Galisteo et al., 2010; Noureddin, Mohsen, & Payman, 2018).

A study with 12 healthy volunteers weighing, at least ,10% more than the ideal body weight, demonstrated that the intake of 10.8 g psyllium along with 100 mL water for 8 days showed a delay in gastric emptying, increased the sensation of satiety, and decreased hunger when compared to placebo. The authors reported that the delayed gastric emptying increased the duration of gastric distension, which can explain the sensation of prolonged satiety (Bergmann, Chassany, Petit, Triki, Caulin, & Segrestaa, 1992).

Brum et al. (2016) investigated the effects of psyllium on satiety when compared to placebo, suggesting the ingestion of 3 different doses before breakfast, lunch, and dinner for 3 consecutive days, using a group of 19 healthy men and 11 healthy women. The psyllium dosages were 3.4 g, 6.8 g, and 10.2 g, respectively, consumed together with drinking water, before meals. All individuals were exposed to all treatments, and the treatment periods were separated by 4 days. Satiety assessments were performed before and after meals and every 30 minutes for 4 hours. The authors reported that the satiety efficacy followed a trend from the higher to the lower dosage (10.2 g > 6.8 g > 3.4 g), with no significant differences for the dosages 10.2 g and 6.8 g. The authors stated that pre-meal supplementation of psyllium was well tolerated and significantly affected satiety, reducing hunger, increasing fullness, and reducing the desire to snack between meals.

Another study investigated the satiety and body weight loss of 200 overweight and obese individuals, male and female, aged 18-70 years, for 16 weeks in a double-blind placebo-controlled trial. The effect of the ingestion of a blend of fibers (3 g psyllium and 1g glucomannan) and placebo, both diluted in 150 mL water and administered 10 minutes before meals, was evaluated. Weight loss was progressive and constant, without weight recovery at the end of the study. Postprandial satiety increased with the consumption of fiber blend when compared to placebo (Salas-Salvado et al., 2008).

The effectiveness of psyllium in weight loss was also verified in a study with obese rats. Rats that ingested the psyllium-supplemented diet for 10 weeks lost weight, decreased lipid production and accumulation in the liver when compared to placebo (Zarzuelo et al., 2010).

The loss of body weight was also verified in 51 patients with type 2 diabetes and chronic constipation, who were instructed to consume cookies with the addition of psyllium for 12 weeks. Each cookie contained 2.5 g psyllium and 55.5 kcal, and the cookie control had 56.4 kcal. The patients were randomized into two groups, each group consuming two cookies together with water or tea, twice a day (morning and afternoon) totaling 10 g psyllium per day. Participants consuming the cookie with psyllium were more likely to reduce body weight when compared to the group that consumed the placebo cookie (Noureddin, Mohsen, J., & Payman,2018).

6. Use of psyllium in food products

The consumer's concern with health has led to an increasing demand for functional products, which has induced the food industry to develop products with health benefits (El Khoury et al., 2012; Küster-Boluda & Vidal-Capilla, 2017). The permanence of a functional product in the market depends on the sensory acceptance by the consumer (Ares, Giménez, & Gámbaro, 2008; Kearney, 2010).

A survey with 333 participants revealed that consumers have an interest in consuming functional foods, and the companies seeking to produce functional foods should encourage the consumers' preferences by advertisements and marketing campaigns (Küster-Boluda & Vidal-Capilla, 2017).

Although fibers have stood out among the functional foods due to its health benefits, it is little consumed around the world, which should be encouraged as a way to prevent diseases (Slavin, 2013).

Studies have shown that the functional properties of psyllium coupled with its gel-forming ability make psyllium a promising ingredient to be incorporated into food products. The food made with the addition of psyllium presents fibers containing appeal, which can be an important advantage in the market (Fradinho, Nunes, & Raymundo, 2015). According to Bernstein, Titgemeier, Kirkpatrick, Golubic, & Roizen (2013), the addition of psyllium to food products may allow consumers to ingest adequate amounts of fiber without increasing the calorie intake, as well as contributing to other health benefits such as cholesterol control, glycemic control, satiety, among others (Brum et al., 2016; Gibb et al., 2015; Solá et al., 2010).

Studies on the addition of psyllium to food products have been carried out in recent years and have aroused considerable interest in baking goods such as biscuits, gluten-free bread, and cakes (Beikzadeh, Peighambardoust, Beikzadeh, Javar-Abadi, & Homayouni-Rad, 2016; Cappa, Lucisano, & Mariotti, 2013; Ladjevardi, Gharibzahedi, & Mousavi, 2015; Raymundo, Fradinho, & Nunes, 2014; Zandonadi, Botelho, & Araújo, 2009).

Raymundo et al. (2014) investigated the incorporation of psyllium in biscuits at concentrations of 3 to 15% as a substitute for flour and the following changes were observed: with the addition of psyllium the cookie darkened, fiber and ash contents increased and protein decreased. A reduction in water activity was noted which could lead to increase of shelf life. The authors reported that concentrations higher than 10% of psyllium addition brought technological restrictions mainly due to the rheological characteristics of the dough, due to the high fiber content it was not possible to shape the cookies. Biscuits with up to 9% psyllium added have promising market potential and may be an alternative for the inclusion of fiber in the diet. At these concentrations the product could receive label information on health claims.

Fradinho et al. (2015) also produced cookies with the addition of psyllium in concentrations of 3 to 9%. The authors reported that the incorporation of psyllium showed an increase in ash content and a decrease in proteins, the cookie thickness was increased and this may be a result of psyllium's ability to retain water. Finally, another change was observed, the decrease in diameter after cooking which may have been due to psyllium's ability to form gel. As for texture parameters, it is observed that the firmness increases with the incorporation of psyllium. The best sensorial acceptance was obtained with 6% psyllium and 50% flour, with the possibility of including health claims on the product label as recommended by the FDA.

Cappa et al. (2013) studied the effect of psyllium and beet fiber on gluten-free bread. The fibers were used in combination as follows: (A) 2.5% psyllium + 0.5% beet fiber; (B) 1.5% psyllium + 1.5% beet fiber. The combined fibers comprised 3% of the total flour. The authors used different amounts of water and analyzed the results after baking. The formulation with psyllium presented a better dough development due to its affinity with water, and a better conservation after 3 days. The concentration of 2.5% psyllium exhibited a better bread quality. The use of fiber positively affected the texture, providing a soft and moist dough. According to the authors, the addition of psyllium may be an interesting alternative in the preparation of gluten-free bread, however, it is necessary to add an adequate amount of water to prevent hardening of the dough and to produce a gluten-free bread with a desirable quality.

Zandonadi et al. (2009) studied the sensory acceptance of gluten-free bread made with the addition of psyllium, using a group of 35 celiac individuals and 35 non-celiac individuals. The wheat flour substitutes were psyllium (3.08%), rice cream (18.56%), corn starch (33.22%), and potato starch (45.14%). Bread was 93% accepted by the celiac individuals and 97% by the non-celiac individuals. Concerning the physicochemical parameters, bread presented reduced energy values and fat, thus psyllium can be used to replace gluten in foods.

In their study, Fratelli, Muniz, Santos, & Capriles (2018) showed that psyllium can be used to improve the dietary fiber content and glycemic response of gluten-free bread without compromising its physical properties and sensory acceptability. The addition of psyllium has improved manual modeling, volume, appearance, and texture. The authors reported that it is possible to add 17.14% psyllium and 117.86% water to obtain an acceptable gluten-free bread, with a fourfold increase in fiber content and a 33% decrease in glycemic response compared with the control formulation. Promising results have been reported by Pejcz, Wojciechowicz-budzisz, & Gil (2018) when incorporating psyllium in bread making, among them, the increase in protein content and greater potential in the antioxidant activity of bread.

Brennan, Derbyshire, Brennan, & Tiwari (2012) investigated the potential of psyllium added in extruded snack foods and the reduction of postprandial blood glucose. The psyllium bran was incorporated at a concentration of 15% in relation to flour and according to results presented this amount of psyllium showed benefits in glucose reduction for more than 120 minutes compared to the control. With this result the authors indicate the use of psyllium as a potential fiber for the reduction in postprandial glucose level in extruded products. The authors did not report whether the addition of psyllium had any impact on the physical properties, composition or acceptability of these products.

In studies by Zbikowska, Kowalska, & Pieniowska (2018), psyllium was used as a partial fat substitute in cookie making and the addition of 3 and 5% increased its hardness and reduced its sensory quality. The addition of psyllium may present changes in physical characteristics and acceptance of food products and in some cases adjusting the percentage of added psyllium may improve such characteristics and promote acceptance (Beikzadeh, Peighambardoust, Beikzadeh, Javar-Abadi, & Homayouni). Rad, 2016; Cappa, Lucisano, & Mariotti, 2013; Pandey, Koruri, Chowdhury, & Bhattacharya, 2016).

Beikzadeh et al. (2016) analyzed the effects of the addition of psyllium on cake making, using the following concentrations for 100 g wheat flour 2.5; 5.0; 7.5; 10.0; 12.5 and 15.0 g. The increase in psyllium concentration led to a reduction in cake volume, due to the water retention by the soluble fibers of psyllium. The increase in water absorption led to an increase in dough viscosity, affecting the air expansion, causing a decrease in cake volume, which was observed for the formulations containing ≥7.5% psyllium. A better sensory acceptance was observed for the samples containing 5% psyllium.

Gupta, Milind, Jeyarani, & Rajiv (2015) prepared a more nutritious pizza base partially replacing wheat flour with isolated soy protein (10%) and psyllium (5%), but the overall quality of the dough was not satisfactory requiring the addition of additives that improved the dough and thus produced a product of acceptable quality. The addition of psyllium contributes to the increase in fiber content.

As reported in some studies the addition of psyllium may present some challenges regarding physical properties (texture and color) and sensory acceptance, but with the adjustment in psyllium addition ratios or the use of additives it is possible to produce higher quality food products. as their addition contributes to fiber increase (Bernstein, Titgemeier, Kirkpatrick, Golubic, & Roizen, 2013; Fradinho, Nunes, & Raymundo, 2015; Gupta et al., 2015). Another issue important to highlight is that in order a psyllium added food product includes a health claim on the label, it must have a minimum amount required by regulatory bodies (Brazil, 1999; FDA, 2012).

Figueroa & Genovese (2019) produced fruit jellies enriched with 3 g fiber *per* 100 g product. At this concentration the product may contain the declaration as a source of fiber. The fibers used were apple, bamboo, psyllium and wheat and had a significant effect on viscoelastic and mechanical properties, color and syneresis. Psyllium-enriched jelly was the only sample that showed no syneresis, but its acceptance was undesirable due to gum consistency. For the production of a jelly with acceptable characteristics, a combination of fibers (apple + psyllium, bamboo + psyllium and wheat + psyllium) was carried out and finally obtained a product with acceptable attributes such as strength, texture, stability, appearance and taste of the gel. In this study, psyllium had the benefit of preventing water loss in the product (syneresis) and contributed to the increase in fiber content.

Psyllium has also been used in products from animal sources, such as yogurt and sausages. Ladjevardi et al. (2015) used PHG (Psyllium Husk gum) in the formulation of low-fat yogurt, and found an excellent sensory acceptance, with maximum firmness, viscosity, and ideal pH for the yogurts formulated with 0.12% PHG and 0.63% fat. The authors reported that an increase in PHG concentration markedly improved the firmness and viscosity, and greatly reduced syneresis. The sensory evaluation revealed that the yogurts manufactured with 0.12% PHG presented higher scores for the attributes aroma, texture, and overall impression when compared to the control, with no significant difference among them.

Pandey, Koruri, Chowdhury, & Bhattacharya (2016) investigated the amount of psyllium to be incorporated into yogurt without affecting the quality and acceptance of the final product. The authors found a higher supply of fiber at the concentration of 0.7% psyllium, but the sensory acceptance test showed a greater overall acceptance of the yogurt containing 0.5% psyllium, with a decrease in pH and acidity throughout the refrigerated storage (0-3 ºC).

Osheba, Hussien, & El-Dashlouty (2013) evaluated the effects of the addition of vegetable colloids extracts (psyllium, carob seed, and orange albedo) in meat sausage when compared to the pectin extract, concerning the quality attributes of the product. To prepare the psyllium gel, 95 mL water and 5 g psyllium was heated at 80 °C for 2 hours and cooled to room temperature, and 15% of this gel was used in the sausage formulation. The sausage was stored for 6 months at -18 °C. The formulation with psyllium showed good results for phenolic compounds and flavonoids, with values of

234.01, 37.67, 12.01 mg/100 g for cholchecien, catechol, and pyrogallol, respectively. The total flavonoids were 536.46 mg/100 g, and hesperidin was the main flavonoid compound, with 442.40 mg/100 g. The authors reported that the production of sausage with the addition of colloids brings benefits to the quality attributes, and especially psyllium may have a therapeutic effect due to its pronounced levels of polyphenols and flavonoids.

The great advantage of incorporating psyllium into foods is that it does not change the flavor of the final product. Its palatable fiber can easily be added to food products, and play an important role in the prevention of cardiovascular diseases (De Bock et al., 2012). Ribas, Cunha, Sichieri, Carlos, & Santana da Silva (2015) reported that foods containing psyllium may be a valuable resource for maintaining low LDL concentrations in the body.

The physicochemical and biological properties of psyllium can be changed using some techniques of chemical modifications such as hydroxypropylation, sulfation and succinylation which result in new psyllium derivatives with improved properties for functional food use (Liu, Xie, et al. ., 2010; Liu, Zhang, et al., 2010; Niu et al., 2012).

Hydroxypropylation and sulfation of psyllium can improve its physicochemical and functional properties without reducing its beneficial effects. These modifications reduce the gelling properties of psyllium, increasing in vitro the capacity of binding to the bile acid which may have a stronger activity to reduce cholesterol. Reduction in gelling capacity occurs due to sulfation and hydroxypropylation of psyllium alter arabinoxylan structure (Liu, Xie, et al., 2010, Liu, Zhang, et al., 2010).

Niu et al. (2012) investigated the effects of succinylation on the physicochemical, functional and health potential properties of psyllium. The authors suggested that a certain degree of psyllium succinyl substitution could improve bile acid binding properties. The study showed that psyllium modified by succinylation technique can decrease plasma LDL cholesterol levels and that the amount to be used of chemically modified psyllium would be lower than unmodified psyllium and this would have less influence on sensory and physicochemical properties of food.

Another study reported the effects of sulphation, hydroxypropylation and succinylation on psyllium gelling, water uptake, swelling and bile acid binding capacities and all three derivatization methods reduced psyllium gelling and swelling capabilities and increased water uptake and bile acid binding compared to the original psyllium. When bile acid absorption is increased in the body, it promotes the conversion of cholesterol to bile acids, reducing total and LDL cholesterol levels, contributing to the reduction of the risk of cardiovascular disease (Niu et al., 2013).

It is worth mentioning that the industrial processing of food can interfere with the benefits of fiber. Many health benefits are only achieved with the high viscosity of psyllium fiber, i.e., the benefits depend on the gel formation, thus it is necessary to consider whether the food production process (extrusion, heat, pressure) can attenuate its efficiency (McRorie & McKeown, 2017).

7. Concluding remarks

Psyllium may play an important role in the food industry, once its incorporation into food products can bring health (cholesterol control, glycemic control and satiety) and technological benefits, including the sensory acceptability and high fiber content of the products. The ability of psyllium to bind with water is an advantage in the production of gluten-free products and low-fat meat products. It is worth mentioning that these products can receive health claim due to the benefits of decreasing fat absorption. However, more research is needed in order to evaluate the variables of industrial production processes that can affect the benefits of psyllium industrial food products.

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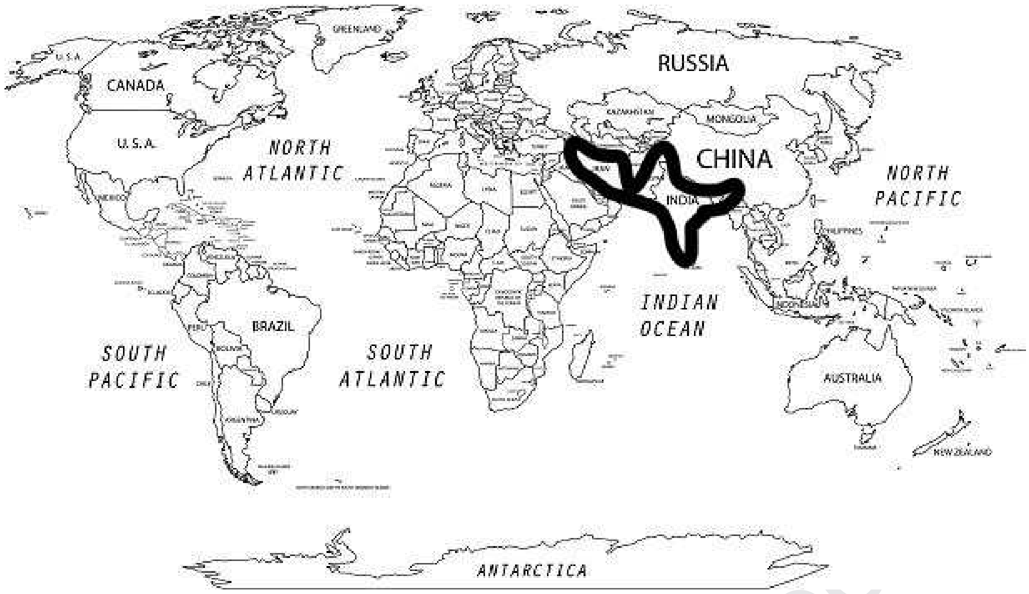

Figure 1. Map showing the main geographical area for the cultivation of the *P. ovata*

Table 1. Nutritional values of psyllium seed husk (*Plantago ovata*)

Component	Units							
	mg/g	g/100 g	μg/g	g/100 g	g/100 g	g/100 g	g/100g	g/100g
Moisture	-	-	-	6.83	-	12.55	6.43	4.22
Ash	33.5	-	8.6	4.07	3.4	2.25	3.85	12.01
Total Protein	35.0	17.4	11.8	0.94	7.1	1.38	2.08*	7.12
Fat	-	6.7	43.2*	-	-	0.95	0.09*	23.47
Fiber	-	24.6	48.5*	-	-	-	76.63*	54.59
Insoluble fiber	-	19.6	-	-	-	4.21	-	-
Soluble fiber	-	5.0	-	-	-	67.20	-	-
Energy	-	4.75	-	-	-	-	-	-
Carbohydrate	-		8.4	84.98	-	82.87	-	30.33
Carbohydrates Composition								
Rhamnose	28.7	-	-	1.5	1.1	-	-	-
Arabinose	203.2	-	-	21.96	20.7	-	-	-
Galactose	41.2	-	-	3.76	4.8	-	-	-
Glucose	45.9	-	-	0.64	2.0	-	-	-
Xylose	503.1	-	-	56.72	50.3	-	-	-
Mannose	22.3	-	-	0.40	1.1	-	-	-
Ribose	1.2	-	-	-	-	-	-	-
Uronicacids	54.1	-	-	-	5.0	-	-	-
References	Marlett and Fischer, 2002	Romero-Baranzini et al, 2006	Bukhsh, Malik and Ahmad, 2007	Guo et al., 2008	Craeyveld, Delcour and Courtin, 2009	Raymund, Fradinho and Nunes, 2014	Qaisrani et al., 2014	Ghani et al., 2016

*Crude; -Not analysed

Table 2. Minerals content of psyllium seed husk (*Plantago ovata*)

Units	Fe	Zn	Cu	Cr	S	Mn	Mg	K	Na	P	Ca	Ni	References
µg/ g	21.7	99.4	59	11.754	-	6.0	63.5	1000	1200	627	1600	0.0213	Bukhsh, Malik and Ahmad et al., 2007
µg/100 g	-	-	-	-	23	-	150	8500	640	140	1500	-	Guo et al., 2008
µg /g	0.175	0.063	0.021	0.323	-	0.231	-	0.105	-	-	-	0.326	Ghani et al., 2016

1015 **Table 3** Psyllium seed husk (*Plantago ovata*) consumption and reduction of total and
1016 LDL cholesterol levels.

Authors	Country	Daily dose (g)	Total cholesterol reduction	LDL cholesterol reduction	Duration of treatment in weeks
Anderson et al. (2000)	USA	10.2	4%	7%	8
Solá et al. (2010)	Spain, France and the Netherlands	14	6%	6.1%	8
De Bock et al. (2012)	New Zealand	6	–	6%	6
Ribas et al. (2015)	Brazil	7	–	11%	8
Pal et al. (2017)	Australia	15	7%	8.1%	52

1017 USA = United States of America LDL = Low density lipoprotein

- The consumption of psyllium reduces the levels of LDL cholesterol.
- Psyllium contributes to the reduction of fasting and postprandial blood glucose concentrations.
- Psyllium supplementation causes satiety, reduces hunger, and reduces the urge to eat.
- Psyllium assists in weight loss.
- Contemporary approaches on the use of psyllium in food products.