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Review

Promising effects of β-glucans on glyceamic control in diabetes

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ABSTRACT

Diabetes is a global burden and a significant public health problem all over the world with an increasing incidence. One of the important factors to prevent and treat diabetes is nutritional therapy. Epidemiological and short-term interventional studies emphasise the association between higher fibre intake and improvements in lipid profile as well as fasting and postprandial glycaemic control. Soluble fibres are more effective for management of diabetes, obesity, dyslipidaemia, hypertension, and different cancers when compared with insoluble fibres. The interest in beta (β)-glucans, soluble fibres has increased due to their multi-functional and bioactive characteristics. They are readiliy available from oat and barley grains. Fermentability and creation of high viscosity solutions in the human intestine constitute the basis of health benefits of β-glucans. β-glucans are important compounds for achieving decreased postprandial glucose and insulin responses, and different mechanisms that would explain glucose and insulin reducing effects have been suggested. The effects of β-glucans on glycaemic control depend on dose, consumption duration, physicochemical features, processing methods, and food form. A significant consideration focuses on consumption of β-glucans and β-glucan-included products that could play an important role in management of diabetes by reducing the risk of diabetes-associated complications.

1. Introduction

Diabetes mellitus is a group of metabolic diseases characterized by hyperglycemia resulting from defects in insulin secretion, insulin action, or both (ADA, 2014). The chronic hyperglycemia of diabetes is associated with long-term damage and failure of various organ systems mainly affecting the eyes, nerves, kidneys, and the heart. nephropathies, retinopathies, neuropathies, ischemic heart diseases, peripheral vascular diseases, and cerebrovascular diseases (Chawla, Chawla, & Jaggi, 2016). It is widely accepted that there are three main types of diabetes, type 1 diabetes, type 2 diabetes and gestational diabetes (GDM). Type 2 diabetes constitutes90%of all cases of diabetes (Ozougwu et al., 2013). According to data from the International Diabetes Federation (IDF) in 2017, there were 451 million adult people with diabetes in 2017 and this is assumed to increase up to 693 million in 2045. The number of children and adolescents with type 1 diabetes (0–19 years) is predicted to be 1,106,500 across the world. The increased incidence of type 1 diabetes in the childhood age group is reported as 2.4% (Onkamo et al., 1999).

Population increase, aging, unhealthy diet, obesity and sedentary lifestyle increase the incidence of type 2 diabetes (James, 2008). Diabetes is treated by insulin injection (type 1), diet, weight loss, and hypoglycaemic agents (type 2) (Chen & Raymond, 2008). However, frequent use of drugs is not cost effective and it is difficult to avoid side effects (Andrade et al., 2015). Therefore, the aim is to achieve glycaemic control through life style changes, in particular, as well as non-pharmacological methods such as physical activity, healthy diet, and functional foods to prevent or relieve hazardous effects and to increase quality of life for diabetic individuals (Cloetens, Ulmius, Johansson-Persson, Åkesson, & Önning, 2012; Andrade et al., 2015).

Nutrition therapy has an integral role in overall diabetes management (Evert et al., 2017). It is reported that medical nutrition therapy can reduce the HbA1c levels by 0.55–2.00% in type 2 diabetes and 0.3%–1.0% in type 1 diabetes (ADA, 2017). Dietary fiber is deemed to be a key component in healthy eating (Kaczmarczyk, Miller, & Freund, 2012). Consumption of foods rich in fibre is recommended for nutritional therapy of diabetes (Dworatzek et al., 2013; Nader et al., 2014). Dietary fibre reduces the glycaemic indexes of foods and decreased glycaemic index causes decreased average blood glucose levels (Nader et al., 2014). Antidiabetic effects of foods, including β-glucans, soluble fibers, have become a focus of interest for many researchers (Cugnet-Anceau et al., 2010; Jenkins et al., 2002; Tessari et al., 2017). In the present review, the effects of β-glucan on postprandial glucose and insulin response as well as diabetes treatment will be discussed.

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1.1. Dietary fibre types and features

Dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine (AACC, 2001). In the simplest form, carbohydrates are divided into two groups according to the digestibility grade in the gastrointestinal tract. The first group (starches, simple sugars, and fructans) are easily hydrolysed through enzymatic reactions and absorbed via the small intestine. Such components are non-structural carbohydrates, non-fibrous polysaccharidesor simple carbohydrates. The second group (cellulose, hemicellulose, lignin, pectin, and β-glucans) is resistant to digestion in the small intestine and they require bacterial fermentation in the large intestine. Such components may be defined as complex carbohydrates, non-starch polysaccharides, or structural carbohydrates. Non-starch polysaccharides are the main constituents of dietary fiber (Căpriţă, Căpriţă, & Julean, 2010). Dietary fiber is classified by solubility in water (soluble vs. insoluble fiber), microbial fermentation in the large intestine (fermentable vs. non-fermentable fibers), and viscosity (viscous (gel-forming) vs. nonviscous fibers), and these properties influence the therapeutic effects of consumption (Fuller, Beck, Salman, & Tapsell, 2016; Holscher, 2017) (Fig. 1). Soluble fibres are dissolvedin water and usually form a gel. They pass through the small intestine without digestion, and are easily fermented by the large intestinal microflora (Lattimer & Haub, 2010). Soluble fibers can be further divided into viscous (gel-forming) or nonviscous types (Chutkan et al., 2012). They can be found oat and barley product, in some vegetables, fruit, and legumes (dry beans, peas, lentils) (Slavin et al., 2009). Cellulose, hemicellulose, and lignin are insoluble fibres that are a great part of the dietary fibres, and they can be found in wheat bran, whole grain bread, and cereals as well as exist in some vegetables such as cabbage and brussel sprouts. Insoluble fibres do not create gel and fermentation is very limited (Lattimer & Haub, 2010).

A sufficient level of dietary fibres in the diet is important to maintain a healthy life and to be protected from certain diseases. Different types of dietary fibre have different effects (Fuller et al., 2016). Soluble fibres are reported to be more effective for management of diabetes, obesity, dyslipidaemia, and hypertension when compared with insoluble fibres. Soluble fibres delay gastric discharge and slow down digestion and absorption functions, causing more short chain fatty acids to be produced by the large intestine bacteria due to high fermentability (De-Mello & Laaksonen, 2009; Kim et al., 2006; Salvado et al., 2011).

1.2. β-Glucans and their characteristics

β-glucans are a heterogeneous group of non-starch polysaccharides, consisting of D-glucose monomers linked by β-glucosidic bonds (Zeković et al., 2005). β-glucans exist in polysaccharide forms consisting of short and medium chains as (1 → 3)/(1 → 4) and (1 → 3)/(1 → 6) bonds, depending on the source (Daou & Zhang, 2012). Macromolecular structures of β-glucans vary depending on the resources obtained and isolation states (Khoury et al., 2012). The β-glucans obtained from grains consist of β(1 → 3/1 → 4) bonds, whereas the β-glucans existing in the cell walls of yeast and fungi include β(1 → 3/1 → 6) bonds (Chen & Raymond, 2008). Bond types of β-glucans, branching pattern and grade, helical formations, molecular weights, polymer loads, water solubility and ring conformations in a solution vary and such variations affect their biological activities (Zeković, Kwiatkowski, Vrvić, Jakovljević, & Moran, 2005; Surenjav, Zhang, Xu, & Zeng, 2006; Volman, Ramakers, & Plat, 2008; Stone, 2009). Fungus and yeast-derived β-glucans consist of β(1 → 3) glycopyranocile molecules as well as side branches bound by β(1 → 6). Such bonds add a branched structure onto the fungus and yeast glucan. Oat and barley β-glucans do not include side branches. Such structural differences provide different functions to β-glucans (Ahmad et al., 2012). The β bonds in the polymer make β-glucan indigestible. However, β-glucans are fermented in caecum and colon (Ooi & Liu, 2000; Topping & Clifton, 2001) (see Fig. 2).

The solubility of β-glucans is highly influenced by their structures (Havrlentova et al., 2011). Highly polymerised (1 → 3) β-glucans are not completely dissolved in water (Degree of polymerisation (DP) > 100). Solubility decreases when polymerisation grade is lower The composition of the side substituted branches also determine the solubilitiy of β-glucan molecules (Khoury et al., 2012). However, viscosities of β-glucans depend on molecular weights, solubilities, and concentrations. High molecular weight β-glucans have a higher viscosity when compared with low molecular weight β-glucans (Theuwissen & Mensink, 2008). The β-glucan of the oat has a higher molecular weight than the β-glucan content of barley (Wood et al., 1998). The most commonly accepted mechanism to reduce cholesterol and blood glucose is increasing intestinal viscosity (Daou & Zhang, 2012). β-glucans have more positive effects on health when compared with other soluble and fermentable dietary fibres due to its characteristic to create highly viscose solutions at lower concentrations (1%) and are stable with pH (Chen & Raymond, 2008).

They naturally exist on the cell walls of plants, in grain seeds, and in

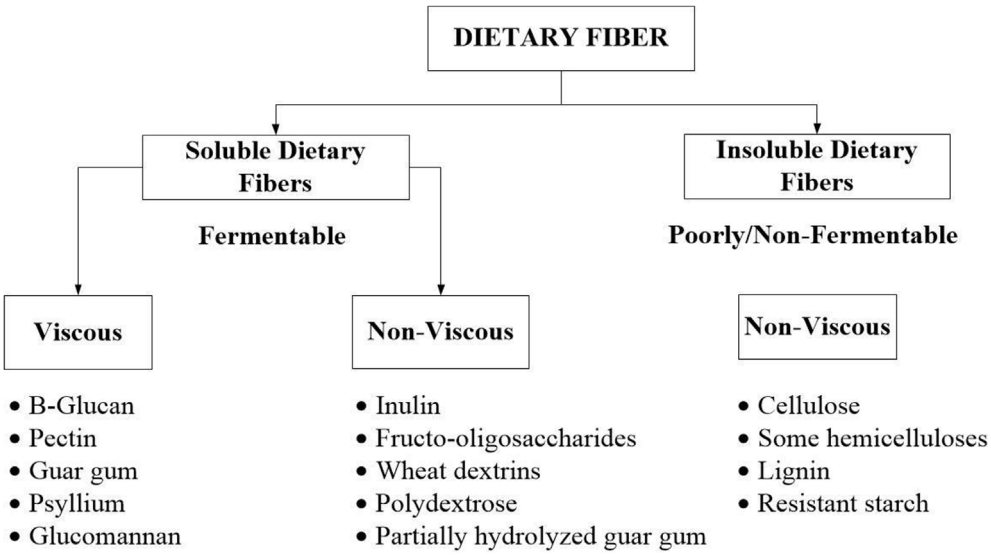

Fig. 1. Classification of dietary fiber according to chemical properties.

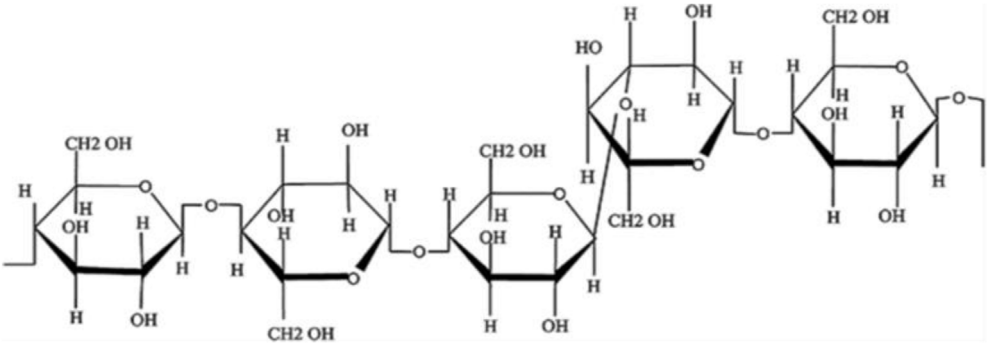

Fig. 2. Basic structure of β-glucans.

some fungi, yeasts, algae and bacteria. Bread yeast (*Saccharomyces cerevisiae*), fungi (*Coriolus versicolor, Lentinus edodes,* and *Schizophyllum commune*), some algae, and some bacteria (*Agrobacterium* sp., *Alcaligenes faecalis)* may be used as a source of β-glucan. They usually exist on the endosperm cell wall of oat and barley (75%) and in bran (10.4%). The highest β-glucan contents among the grains (g/100 g dry weight) were reported for barley (2–20 g; 65% soluble) and oat (3–8 g; 82% soluble). Other grains include much lower β-glucan levels. The β-glucan quantity of sorghum is 1.1–6.2 g, of rye is 1.3–2.7 g, of corn is 0.8–1.7 g, of triticale is 0.3–1.2 g, of wheat is 0.5–1.0 g, of hard wheat is 0.5–0.6 g, and of rice is 0.13 g (Khoury et al., 2012).

1.3. β-Glucans and health effects

β-glucans have useful effects for prevention, treatment, and management of diabetes as well as cardiovascular diseases, obesitiy, and hyperlipidemia. In addition, they stimulate immune function through monocyte/macrophage activation, increased immunoglobulin, natural killer cells (NK), T cell count to develop resistance against cancer, and infectious and parasitic diseases (Daou & Zhang, 2012). The β(1 → 3/1 → 4) conformation of these polysaccharides (as usually exists in oat) has a metabolic potential whereas, the β(1 → 3/1 → 6) conformation tends to have immunological potential. However, both structures play a role in both metabolic and immune activity (Andrade et al., 2015). Cholesterol lowering effects of oat β-glucans have been shown (Othman et al., 2011). In a meta-analysis where outcomes of 30 studies were reviewed, oat and barley β-glucan intake caused a significant decrease in total cholesterol, LDL cholesterol, and triglyceride/triacylglycerol levels (Tiwari & Cummins, 2011). Glucans reduce reabsorption of bile acids and increase transportation to the large intestine due to high viscosity, activate 7α-hydroxylase to cause cholesterol elimination from the body, and increase up-regulation of low density lipoprotein receptor (LDLR), thus enabling transport of LDL to hepatocytes and transformation of cholesterol into bile acids Nilsson et al., 2007; Chen & Raymond, 2008). Another cholesterol lowering effect of β-glucans is their fermentation capacity. Fermentation of oat and barley change concentrations of bile acids in the intestinal tract and provide production of short chain fatty acids, which have a hypercholesterolaemic effect (Chen & Raymond, 2008) β-glucans also increase intestinal viscosity and slow down glucose absorption rate, reduce postprandial insulin concentrations and reduce hepatic 5-hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) reductase activity as well as cholesterol synthesis stimulated by insulin (Daou & Zhang, 2012).

To achieve such health benefits, the Food and Drug Administration (FDA) recommends to consume at least 0.75 g per portion or 3 g per day of oat and barley β-glucan (FDA, 1996). It was shown in individuals with type 2 diabetes that consumption of bread with oat β-glucan in the amount of 3 g/day for 3 weeks caused a reduction of 5% in serum total cholesterol and 10% in LDL cholesterol (Liatis et al., 2009). Andrade et al. (2015) performed a systematic review and reported that β-glucan intake of 3–6 g/day for 2–4 weeks provided a decrease in triglyceride, total and LDL cholesterol levels, and an increase in HDL cholesterol levels. In a previous meta-analysis, consumption of at least 3 g of oat β-glucan with a molecular weight ≥100 kDa for 2–12 weeks reduced LDL and total cholesterol levels and increased HDL cholesterol in hypercholesterolaemic individuals (Whitehead et al., 2014).

A β-glucan intake of ≥3 g by individuals with type 2 diabetes for at least 3 weeks was reported to cause a decrease in body mass (Liatis et al., 2009; Reyna et al., 2003). Viscosity of soluble fibres plays an important role in appetite control and feeling of fullness. High-lyviscosity β-glucans delay gastric discharge, slow down digestion and absorption of nutrients due to reduced effect on enzymatic activity and mucosa absorption, cause earlier fullness, and decrease energy intake. Furthermore, short chain fatty acids generated as a result of β-glucan fermentation regulate release of different gastrointestinal hormones that play an important role in signaling the sensation of fullness. Another mechanism of soluble fibres, including β-glucans, to provide a sense of fullness is reported to be through reduced glycaemic and insulinaemic responses (Khoury et al., 2012; Marciani et al., 2001).

Peptide YY (PYY), glucan-like peptide 1 (GLP-1), cholecystokinin, and ghrelin hormone levels are effective in appetite control and are regulated by short chain fatty acids. The PYY hormone reduces appetite and food intake (Khoury et al., 2012). It is reported that daily intake of 4–6 g of β-glucan increases PYY, which has a significant role in appetite regulation and obesity management (Beck et al., 2009a).

It is reported that β-glucans act to reduce blood pressure to within normal limits (Cloetens et al., 2012). In a study performed on hypertensive and hyperinsulinaemic individuals, a significant decrease in systolic and diastolic blood pressures was shown in the group consuming oat for 6 weeks (standardised to 5.52 g/day β-glucan) when compared with the group consuming low fibre grains (total fibre < 1 g/day) (Keenan et al., 2002). Insulin resistance is a basic mechanism that contributes to hypertension (Ferri et al., 1999). β-glucans modulate insulin metabolism and contributes to regulation of blood pressure. The decrease in plasma cholesterol levels observed after consumption of β-glucans is also associated with improvements in endothelial-originated vasodilatation. Increased body weight is a strong risk factor for hypertension. β-glucans provide weight loss and reduces blood pressure (Andersan et al., 1995; Neter et al., 2003).

The immune-stimulating effects are possibly due to activation and differentiation of cytotoxic macrophages and helper T cells. Moreover, regulation of humoral and cellular immunity is well known. Cellular immunity is modulated through interactions with cell surface receptors such as complement receptor 3 (CR3), lactosylceramide, selected scavenger receptors, and dectin 1 (βGR). As a result of such interactions, activity of many determinants such as cytokines, chemokines, transcription factors, and growth factors are modulated. β-glucan that is taken-up into the cell by macrophages through dectin-1 is fragmented in the cell. It is then transported to the bone marrow and reticulo-endothelial system and released. Such small β-glucan fragments are taken-

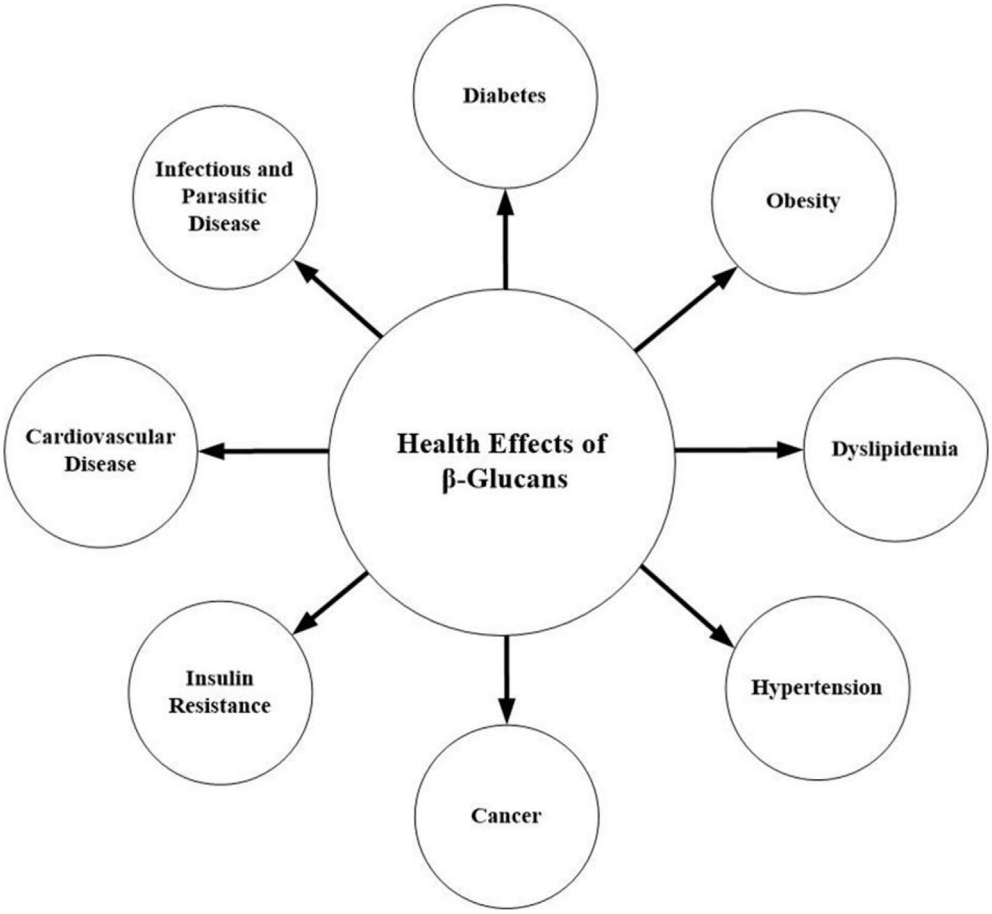

Fig. 3. Health effects of β-Glucans.

up by granulocytes, monocytes, or macrophages through CR3. The immune response then starts, and one of these activities is phagocytosis of monoclonal antibody-labelled tumor cells (Chan et al., 2009) (see Fig. 3).

1.4. β-Glucans and diabetes

β-glucans are important compounds that contribute to glycaemic control (Chen & Raymond, 2008). European Foods Security Agency (EFSA) expressed a positive opinion of their health potential, stating "foods including oat and barley β-glucan reduce postprandial blood glucose" based on scientific evidence (EFSA, 2011).

Significant improvements in glycemia were observed in the glycemic status of diabetic rats treated with beta glucan (Gao et al., 2012; Lo et al., 2006). Vieira Lobato et al. (2015) observed 30% reduction in plazma glucose concentration in diabetes-induced rats treated with leaven beta-glucans.

Less β-glucan quantity may be sufficient to achieve a reduction in postprandial glucose and insulin responses in healthy individuals as well as in individuals with type 2 diabetes and hypercholesterolaemia when compared with other fibres (Hallfrisch, Scholfield, & Behall, 1995; Makelainen et al., 2007; Tappy et al., 1996).

The effects of β-glucans on glycaemic control may vary depending on the consumption quantity, consumption period, physicochemical characteristics, processing methods, and form of the foods included (Khoury, Cuda, Luhovyy, & Anderson, 2012; Cloetens et al., 2012).

A significant association was detected between β-glucan quantity of grains and plasma glucose peak as well as the area under the curve (AUC) for glucose. A dose-dependent linear decrease was reported between consumption of bread including barley β-glucan with different quantities (0.1–6.3%) and glycaemic responses (Cavallero et al., 2002). In a previous study conducted with individuals with type 2 diabetes, consumption of a breakfast cereal and bar including 6.5 g and 8.1 g of β-glucan, respectively, created a lower postprandial glucose response than oat bran breakfast cereal including 4.4 g of β-glucan (Jenkins et al., 2002). Similarly, the AUC for plasma glucose created by oat bran cereals including 3 g of β-glucan during the postprandial period was larger than the area created by oat bran flour including 9.4 g of β-glucan (Tapola et al., 2005). In line with aforesaid results, when breakfast cereals including 0.0, 2.5, 5.0, 7.5, or 10.0 g of β-glucan were consumed by individuals with type 2 diabetes, a significant decrease in blood glucose levels was detected in the individuals consuming 10.0 g of β-glucan (Kim et al., 2009).

A systemic review reported that β-glucan intake below 3.5 g/day did not provide significant decreases in glycaemia and glycolised hemoglobin levels, though intake of ≥6 g/day for at least for 4 weeks would be useful (Andrade et al., 2015). The EFSA stated that foods including at least 4 g of oat or barley β-glucan per 30 g of carbohydrate would reduce the postprandial glycaemic response (EFSA, 2011).

Higher doses of β-glucans should be taken to change glycaemic homeostasis in healthy individuals. In a previous study conducted on diabetic patients, glucose levels were reduced in individuals whom added 3 g of β-glucan into their breakfast (Tapola et al., 2005). However, despite the results in diabetic individuals, the postprandial glycaemic response was not affected in healthy individuals consuming 3 g of β-glucan (Granfeldt et al., 2008). In another study, in comparison to healthy individuals with and without consumption of muesli including 4 g of oat β-glucan, blood glucose responses of the β-glucan consumers were detected to be lower (Hlebowicz et al., 2008).

Duration of consumption is a determinant on the efficiency of β-

glucans effects on blood glucose levels. It was reported that β-glucan consumption of 3 g/day for 12 weeks provided a glycaemic decrease of 46% when compared with the control group; however, consumption of β-glucan in the same quantity for 4 weeks or consumption of 3.5 g/d for 8 weeks were not effective on glycaemia (Cugnet-Anceau et al., 2010; Kabir et al., 2002; Pick et al., 2008). Acording to a meta-analysis of Shen et al. (2016), oat β-glucan consumption of 2.5–3.5 g/day for 3–8 weeks significantly reduced fasting plasma glucose and HbA1c levels in individuals with type 2 diabetes when compared with the control group; however, fasting plasma insulin concentrations were not affected. In a study conducted on adults with type 1 diabetes, 1.5 g of β-glucan taken before each of the three meal courses for 2 weeks was well-tolerated; however, this did not cause a general improvement on glycaemic control or glycaemic parameters; in such case, the cause was reported as less consumption quantity as well as shorter consumption period (Frid et al., 2017).

The form of the food including β-glucan also has an effect on glycaemic regulation (Ames & Storsley, 2015). A previous study observed that addition of high quantities of β-glucan (5.2 g) into fettuccini pasta in healthy individuals did not significantly reduce postprandial blood glucose levels when compared with consumption of fettuccini pasta solely. The cause was reported to be due to the pasta made of wheat having a lower glycaemic response (Holm et al., 1992). From this point of view, the effects of β-glucan added into a mixed meal as a fibre source on glucose metabolism are difficult to determine (Nazare et al., 2009). Depolymerisation and/or decreasing solubility in the food decreases the reducing effect of β-glucan on postprandial glycaemic responses. Freezing/defrosting cycles or gelation processes cause a decrease in solubility of β-glucan (Khoury et al., 2012). The molecular weight of the β-glucans affect the glycaemic state. In a previous study, a beverage including oat β-glucan (5 g) with a molecular weight of 7,0000 Da (Da) provided lower postprandial glucose and insulin levels when compared with a beverage including barley β-glucan (5 g) with a molecular weight of 4000 Da (Biörklund et al., 2005).

Low glycaemic index diets were associated with a decrease in insulin secretion in individuals with type 2 diabetes and a decrease in the need for daily insulin injections in individuals with type 1 diabetes (Brand-Miller et al., 2003). In a study carried out on males with type 2 diabetes, adding 3 g of oat β-glucan into a high glycaemic index breakfast for 4 weeks reduced plasma glucose peaks significantly when compared with a high glycaemic index breakfast (Kabir et al., 2002). In another study on individuals with type 2 diabetes, each 1 g of β-glucan added into a meal including 50 g of carbohydrate reduced the glycaemic index by four units (Jenkins et al., 2002).

Similar to the glycaemic state, the quantity of consumption of β-glucans is very important for the insulin response pattern (Khoury et al., 2012). A continuous decrease was observed in insulin release depending on β-glucan quantity in the oat consumed by over-weighted individuals, and 3.8 g of β-glucan has important effects (Beck et al., 2009b). Some studies found that effect of β-glucans on insulinaemia is independent from glycaemic effects (Bourdon et al., 1999; Juntunen et al., 2002). A comparison in healthy individuals using consumption of pasta enriched with barley including 5 g of β-glucan revealed significant decreases in insulinaemia compared to the control group without any effect on glycaemia (Bourdon et al., 1999). Similarly, healthy individuals consuming 50 g of rye bread including 5.4 g of β-glucan achieved a decrease in postprandial insulinaemic responses compared with the control group; however, the same effect was not observed on glucose responses (Juntunen et al., 2002). The aforesaid studies suggest the hypothesis that low glycaemic index pasta and rye bread could reduce the effects of β-glucan on glucose responses. According to the results of metaanalysis conducted by Bao, Cai, Xu, and Li (2014) long term (≥8 weeks) β-glucan consumption in healthy individuals or individuals with metabolic diseases significantly reduced the fasting plasma insulin concentrations.

It was reported that high dose soluble fibre intake reduces hypoglycaemic episodes during hunger periods (Giacco et al., 2000). In a study conducted with individuals with type 2 diabetes, 8.8 g of β-glucan intake per day modulated the insulin and glycaemic increases within the first 40 min of the glycaemic test; however, consumption of such a quantity caused higher levels of glucose at 150 and 180 min when compared with the control group (Tappy et al., 1996). However, a study carried out with children with type 1 diabetes did not observe any effect of night-time snack on nocturnal hypoglycaemic blood glucose levels (Rami et al., 2001).

Studies investigating the effects of β-glucan intake on the individuals with type 1 diabetes are very limited (Frid et al., 2017; Rami et al., 2001). The limited number of studies carried out on type 1 diabetes may be caused by use of this fibre type for obesity and type 2 diabetes in general (Beck et al., 2009b; Braaten et al., 1994). Furthermore, since individuals with type 1 diabetes receive exogenous insulin injections, evaluation of the effects of β-glucan on blood glucose may be considered difficult in such a population. However, promising results were obtained in studies conducted on animals with type 1 diabetes. In such studies, β-glucan was found to provide an improvement in glycaemic control and antioxidant profile, which plays a fundamental role in reduction of the oxidative stress concomitant with diabetes (upregulation of superoxide dismutase (SOD) and catalase (CAT) in the liver and kidneys), as well as to increase Akt kinase levels and reduce destruction of pro-caspase-3. Moreover, it was reported that β-glucans activate the survival pathway and provides systematic recovery by increasing the resistance of organisms at the onset of diabetic complications (Mihailović et al., 2013a, 2013b).

1.5. The effects of β-glucan intake on glycosylated haemoglobin (HbA1c)

Hemoglobin A1c (HbA1c) is an alternative parameter in diagnosis and monitoring of diabetes. HbA1c is a measure used for control of long term blood glucose in proportion to blood glucose levels for the previous 2–3 months (Cloetens et al., 2012). In a randomised, parallel, double-blind study conducted on individuals with type 2 diabetes, a significant decrease was detected in HbA1c levels as a result of consumption of the bread enriched with 3 g of β-glucan for 3 weeks (Liatis et al., 2009). Tessari and Lante (2017) had individuals with type 2 diabetes consume a functional bread that was specifically prepared [low starch, rich in fibre (7 g/100 g) and β-glucan/starch ratio (7.6:100, g/g)] for 6 months. At the end of the study, a decrease was detected in HbA1c levels as well as postprandial and mean plasma glucose levels (0.52%) in the treatment group when compared with the control group. Another study was conducted on 16 diabetic males provided a diet that met the nutritional requirements recommended by the American Diabetes Association (ADA) to one group and a low energy diet to the other group. In the low energy diet group, β-glucan was used instead of fat replacement and HbA1c levels of those who had a low energy diet decreased more than the other group at the end of 4 weeks (Reyna et al., 2003). However, in some long-term intervention studies, there was no significant change reported in HbA1c levels of individuals with type 2 diabetes who consumed β-glucan (Cugnet-Anceau et al., 2010; Kabir et al., 2002).

1.6. The insulin and glucose reducing mechanisms of β-glucans

There are many mechanisms explaining the glucose and insulin reducing effects of β-glucans. One of these mechanisms is the ability of β-glucans to form a viscous solution which slow the gastric emptying rate and lengthen intestinal transit time, decreasing digestion and absorption of glucose. When the viscose layer is high, glucose uptake is less (Ames & Storsley, 2015; Andrade et al., 2015). High digesta viscosity reduces enzyme diffusion and stimulates the formation of the unstirred water layer, decreasing glucose transport to enterocytes (Khoury et al., 2012). This causes a net decrease in the rate of glucose absorption into the blood, reducing postprandial insulin concentrations

(Silva et al., 2017). The delay in gastric discharge following consumption of β-glucan was revealed by clinical studies. The exogenous glucose quantity detected in the plasma for 120 min was found to be 18% lower in overweight individuals who had oat β-glucan intake (5 g) than the control group (Nazare et al., 2009). Another study added ^{13}C-labelled glucose into a meal including 8.9 g of β-glucan for 3 days, and it was detected that such a meal reduced exogenous ^{13}C-glucose detection rate by 21% when compared with the control meal (Battilana et al., 2001).

Another descriptive mechanism for the protective effects of fibre on glucose and insulin homeostasis is the formation of short chain fatty acids as a result of anaerobic fermentation of soluble fibres like β-glucan in the colon (Daou & Zhang, 2012; Khoury et al., 2012). Short chain fatty acids might be mediating the postprandial glucose effects at subsequent meals (Ames & Storsley, 2015). Short chain butyric acid, propionic acid, and acetic acid were shown to increase the expression of insulin sensitive glucose transporter type 4 (GLUT-4) by activating peroxisome proliferator receptor (PPAR) γ (Song et al., 2000). GLUT-4 is responsible for glucose transportation into adipose tissue and, thereby, reduction of plasma blood glucose levels (Huang et al., 2007). Abbasi, Purslowb, Toshc, and Bakovic (2016) reported in their study that expression of sodium glucose transporter-1 (SGLT-1) and glucose transporter-2 (GLUT-2) was achieved by increasing the concentrations of oat β-glucan. GLUT-2 has an important role in regulation of blood glucose. The glucose that is absorbed after meal and included into the portal circulation is transported to the pancreas and liver via GLUT-2. SGLT-1 is mainly present in the small intestine as well as distal side (segment S3) of the proximal tubule in the kidneys and is responsible for reabsorption of glucose (Röder et al., 2014).

Another possible mechanism of β-glucans to reduce blood glucose levels is providing a signaling pathway through activation of PI3K/Akt. Decreased PI3K/Akt activity was reported to play an important role in pathogenesis of diabetes. It was shown that administration of β-glucans increase PI3K/Akt activity, which decreases in diabetes, through several receptors. The receptors stimulated by β-glucan include dectin-1, CR3, lactocylceramide, scavenger receptors, and toll-like receptors (Chen & Raymond, 2008). These receptors are considered to be important, especially for identification of β-glucan polymers having (1→6) branching on a (1→3) chain in particular (Brown et al., 2002; Hahn et al., 2003).

2. Conclusions and recommendations

Prevelance of diabetes is increasing worldwide. Thus the development of new alternatives for diabetes management is significiant. The intake of fiber and especially β-glucans, become an important alternative for diabetes control. The fact that β-glucans are safe natural product and their cost is lower than drugs may give rise to the thought that β-glucans can be used in treatment and prevention of disease. β-glucans are the principal fiber present in barley and oat. Fermentation ability and highly viscosity solution formation of β-glucans in the human gut is the basis for health benefits. These benefits include lowering postprandial glucose and insulin responses, decreasing cholesterol levels, potentiating the feelings of satiety. The results of clinical studies indicate that β-glucans effective in the diabetes treatment, by slowing down the gastric emptying and decreasing the absorption of glucose by enterocytes. Thus, β-glucans could produce new approach for the treatment of diabetes. The quantity of β-glucans, consumption period, food form, processing methods, and molecular weight are the factors affecting glycaemic control. Detection of the accurate dose and duration for use is important for treatment. It is reported that, long term consumption of β-glucan at ≥ 3 g/day may provides more benefits in the diabetes management. However, more studies investigating the quantitiy, consumption period, molecular weight, the food vectors, and the tolerability of β-glucan are needed to clarify the antidiabetic effects. Studies investigating the effect of dietary or supplementary β-glucan on glyceamic control are also required. In addition, well-design human study investigating the long-term benefits of β-glucan consumption in the diabetic population are higly recommended. β-glucans are diverse in their structure and some may be not effective on diabetes. Therefore, characterization of structure features essential for antidiabetic effects. Processing condition used in the manufacturing and preparation of β-glucan containing foods impact β-glucan viscosity. Thus, processing effects should be considered when desinging future studies, and it is very important to establish standardised food processing, and preparation methodologies to create β-glucan containing foods. Also, there is not sufficent data about the effect of β-glucans on glyceamic response in type 1 diabetes. Thus, further inestigations are needed to detect effects of β-glucans on type 1 diabetes.

Conflicts of interest

The authors declare no conflict of interest.

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