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Effect of soluble dietary fibre on postprandial blood glucose response and its potential as a functional food ingredient

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ABSTRACT

Soluble dietary fibre (DF), including β-glucan, guar gum, psyllium and alginate, reduce the absorption rate of glucose after the consumption of a high carbohydrate load through its beneficial viscosity properties. The addition of DF to high carbohydrate liquids and foods has shown significant reductions in postprandial glucose absorption albeit palatability issues at the concentrations required to see the beneficial effect have limited their applications as a functional food ingredient. Changes in the physiochemical properties of the DFs following food processing negatively impacts on DF viscosity and ultimately reduces efficacy. Research is focusing on exploring processing procedures that minimize disruption to these physicochemical properties such as changes to temperature, molecular weight and contact times. Furthermore, the development of novel composite DF blends that draw on individual characteristics is a novel method of utilizing DF as a functional food ingredient for its glycemic lowering ability.

1. Introduction

Low consumption of dietary fibre (DF) is well recognized as being associated with a higher incidence of several chronic diseases (Burkitt & Trowell, 1975) including cancer (Park, Brinton, Subar, Hollenbeck & Schatzkin, 2009), cardiovascular disease (Threapleton et al., 2013), obesity (Tucker & Thomas, 2009) and type 2 diabetes (T2DM) (Meyer et al., 2000). Increasing intake of DF, particularly those DF with evidence to reduce rapid elevations in postprandial glucose, is recommended in the prevention and management of these chronic conditions (SCAN, 2015). The functional food industry strives to include such DFs in their products to reduce the glycemic index (GI) without reducing or substituting the sugar content in products.

There is a plethora of research to suggest that the main physicochemical property related to the beneficial properties associated with DF and glycemic control is viscosity (Jenkins et al., 1978) and its ability to adjust the rate of gastric emptying (Schneeman, 2002; Yao & Roberts, 2001). A reduction in glucose absorption (Brennan, 2005), a lowering of GI in ingested foods, an increase in chyme viscosity and improved hormonal responses to nutrients are all viscosity-related mechanisms that have been proposed to contribute to the beneficial glycemic effect of soluble DF when consumed in conjunction with a high carbohydrate load (Jenkins et al., 1981). It has also been reported that many of the soluble fibres discussed also have the potential to be fermented in the colon. It has been suggested that fibre fermentation products could potentially impact postprandial glycaemic control and gut motility, however this will not be discussed in this paper as it is extensively reviewed elsewhere (Brighenti et al., 2006). This viscosity functionality has been well demonstrated by human intervention studies (Brownlee, 2011; Paquin, Bédard, Lemieux, Tajchakavit & Turgeon, 2012; Thondre, Shafat & Clegg, 2013). Several DFs have been investigated regarding their role in attenuating the postprandial blood glucose response (PBGR) including β-glucan, guar gum, psyllium, resistant starch, alginate and more recently the composite DF blend PolyGlycopleX (PGX). Whilst many of these components are present in sufficient amounts in whole foods, there are increasing efforts to isolate the fibre components for use as supplemental DF in the functional food industry. While these DFs have shown efficacy in dietary studies, their application in the food industry remains limited due to changes in physicochemical properties brought about by processing e.g. heating and extrusion processes (Tosh et al., 2010). Processing can be intentionally used by the food industry to modify fibre structure to reduce molecular weight with the aim of altering the physicochemical properties to alter the sensory characteristics of the fibre/fibre ingredient. The processing and alteration of fibre structure can improve its functional properties, for example the hydrolysation of insoluble guar gum to partially

Abbreviations: DF, dietary fibre; PBGR, postprandial blood glucose response; T2DM, Type 2 diabetes; GI, glycemic index; MW, molecular weight; PGX, PolyGlycopleX; AUC, area under the curve

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hydrolysed guar gum (PHGG) which has improved solubility and gut fermentability. It is, however, significantly less viscous and thus could potentially reduce its bioactivity associated with viscosity including its impact on postprandial glucose and cholesterol lowering effects (Kapoor, Ishihara, & Okubo, 2016). In light of the existing challenges to differentiating guar gum from its hydrolysed counterpart PHGG, there is a need to characterize the impact of processing on fibre molecular weight and how the subsequent changes may impact the fibre's viscous associated functionality for proposed health claims and subsequently decide if there is a need for differentiation upon processing. The beneficial impact of DFs on postprandial glucose absorption is negatively impacted with increasing levels of food processing thereby reducing its efficacy. As a result, research is focusing on identifying food manufacturing processes that would preserve these beneficial properties. Furthermore, there is increasing interest in developing novel composite DF blends that would maintain these properties even after extensive processing. This review will provide a comprehensive overview of the literature to date, discussing the efficacy, limitations, differences and challenges of using various soluble DFs as a functional food ingredient with applications in glycemic control.

2. Methods

2.1. Study selection: retrieval procedure and criteria

Search strategies included computer searches of databases. Abstracts from peer reviewed journals were reviewed and if they met the criteria (outlined below), the full article was retrieved. The following databases were searched from 1970 to 2017 for articles in English: MEDLINE, Web of Science, PubMed, Nutrition and Food Science and Scopus. Keyword databases were searched using the following terms: dietary fibre, dietary fiber, fibre, fiber, non-digestible carbohydrate, soluble, postprandial glucose absorption, postprandial blood glucose response, postprandial glycaemia, viscosity, molecular weight, processing, healthy, human, intervention trial. Abstracts were screened and included in the review if they met the following criteria: (i) A soluble fibre component was investigated, including but not limited to: β-glucan; psyllium; pectin; gums; alginate; resistant starch; galactomannan; inulin and arabinoxylans, (ii) effects on postprandial glycemia investigated, (iii) clinical intervention studies on healthy human subjects only, (iv) information on available carbohydrate and fibre dosage and (v) study may or may not report on the effect of processing affecting physicochemical processes such as viscosity and molecular weight. Where available, information regarding insulin response and GI was extracted from the data. Subject information including age, gender and BMI and information regarding food format and food processing was also collected. Studies were excluded if (i) whole text not available for review, (ii) direct effect on blood glucose was not analysed, (iii) an acute time perspective not studied (~3 h post-consumption) and (iv) the available carbohydrate was not similar between products (carbohydrate was replaced, reducing total amount available).

3. Dietary fibre and postprandial glucose absorption

There is continuously emerging knowledge of the health benefits associated with DF consumption, including its cholesterol lowering actions, effects on the digestive system and reductions in the glycemic response as a direct result of their physiological properties, in particular viscosity. Owing to its viscosity properties, DF is hypothesized to play a role in reducing the rate of gastric emptying and in forming a physical barrier between intestinal content and enterocytes together resulting in a reduced rate of glucose absorption (Anttila, Sontag-Strohm & Salovaara et al., 2004; Mälkki, 2001; Rayner, Samsom, Jones & Horowitz, 2001).

There are conflicting reports with regards to the impact of soluble fibre on gastric emptying and whilst there is a general agreement that soluble DF delays gastric emptying, the extent of its actual contribution to delayed postprandial glucose absorption remains to be conclusively determined (Repin et al., 2017). This is a particularly challenging task as fibre type, dose, molecular weight (MW) and mode of consumption (liquid /solid) are all likely to influence gastric emptying. It must be noted that many studies in the literature attribute fibre-induced reduction of postprandial glucose absorption to gastric emptying without empirically measuring this parameter and thus there is a need for substantiation within the studies.

Intestinal uptake of glucose (& galactose) is predominantly facilitated by Na+/glucose cotransporter SGLT1 whilst fructose uptake is facilitated by GLUT5 which are expressed on the apical surface of the small intestinal enterocytes (Baud et al., 2016; Jang et al., 2018). The fibre induced viscosity within the gut is proposed to slow the rate of arrival of sugar to the intestinal lumen and limit sugar accessibility (glucose, galactose and fructose) to their respective enterocyte receptors resulting in delayed uptake and associated postprandial glucose response.

Chronic early elevations followed by late depressions in postprandial glucose concentrations are associated with the development of insulin resistance and in the aetiology of T2DM (Bhupathiraju et al., 2014). Dietary assessment studies have shown that overweight and obese individuals have poor dietary habits with excessive consumption of refined foods with a high GI (Malik et al., 2010). Ingestion of high GI products ultimately leads to rapid absorption and elevations in blood glucose concentrations. Consuming DF together with these high GI products will not reduce the total amount of glucose absorbed, it will however reduce the rate at which absorption occurs, thus reducing early elevations in PBGR. Therefore, incorporating DF as a functional food ingredient may have particular value in the prevention of obesity and T2DM (Cho, Qi, Fahey & Klurfeld, 2013; Hodge, English, O'Dea, and Giles, 2004; Slavin, 2005).

There is extensive research investigating β-glucans and its postprandial blood glucose lowering effects however guar gum, psyllium, alginate and more recently the composite soluble fibre PGX have all shown promising results with some showing greater efficacy than others outlined in Table 1. A significant amount of research has also been carried out investigating resistant starch. Resistant starch is an insoluble DF which has viscous properties that enable it to function in a similar way to other soluble DFs showing efficacy in clinical studies (Table 1) Several other soluble fibres have shown efficacy however evidence is limited for each (Table 1).

4. Soluble dietary fibres

4.1. β-glucan

β-glucans are one of the most abundant and commonly consumed soluble DFs found in cereal grains, mainly oats (3–8% dry weight of which 82% is water-soluble fraction) and barley (2–20% of dry weight of which 65% is water-soluble fraction) as well as mushrooms (8–27% of dry weight of which < 10% is water soluble) (El Khoury et al., 2012, Cheung, 2013). Cereal derived β-glucans comprise of glucose polymeric chains with β-(1,3) and β-(1,4) linkages ranging from ~150 to 245 kDa whilst mushroom derived beta glucan is also known to contain β-(1,6) linkages and ranges from 9.6 to 298 kDa (Chen et al., 2014) (Table 2). These structural and chemical differences between cereal and mushroom β-glucans contribute to the disparity of their physicochemical properties and associated water solubility (Napolitano et al., 2006). Cereal derived β-glucans are amongst the most widely studied soluble fibre with regards the PBGR. Mechanism of action attributed to these effects include its ability to increase the viscosity of the alimentary bolus thus slowing gastric emptying and as a result lengthening intestinal transit time (Jenkins et al., 1978; Wood, 1990; Johansen, Knudsen, Sandström & Skjøth, 1996). Early work by Wood (1990)