Soluble Dietary Fibre and Type 2 Diabetes – Mechanisms of Action and Food

Professor Douglas Goff

Scientia

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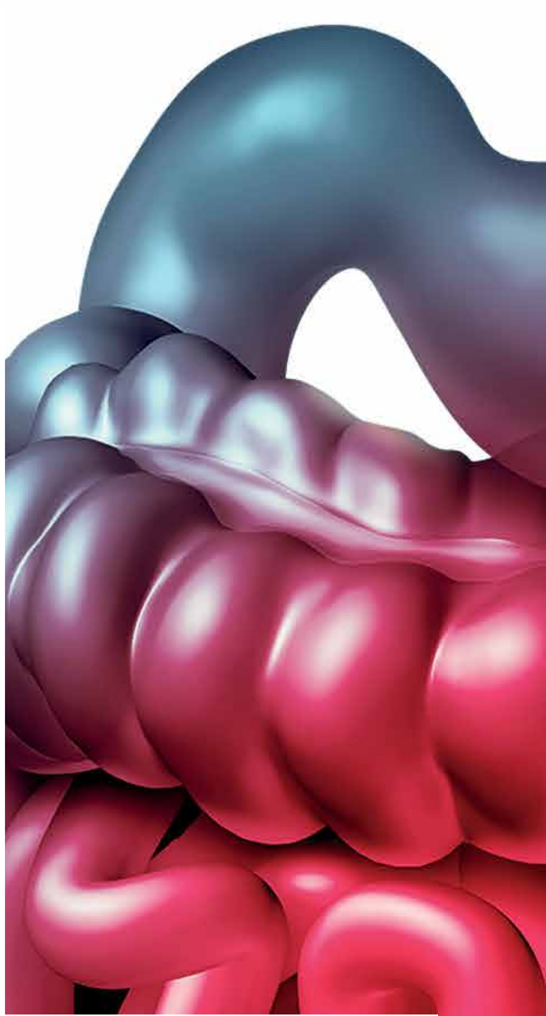


There are numerous health benefits related to eating fibre-containing foods, including lowering the levels of serum glucose and lipids, thus reducing the risk of type 2 diabetes and heart disease. Furthermore, by creating an increased feeling of fullness, eating fibre-rich foods reduces caloric intake and obesity. **Professor Douglas Goff** from the University of Guelph, Ontario, Canada, researches the supplementation of food with fibre and the specific mechanisms of beneficial action, with a focus on blood glucose reductions after eating a carbohydrate-rich meal. Along with his team, his goal is to define the relationship between the molecular structure and physiological functionality of soluble dietary fibres.

Dietary Fibre and Health

The health benefits of dietary fibre consumption are well-documented, including improved colonic health, enhanced gastro-intestinal immunity, and a decrease in blood glucose and lipid levels. Decreased blood glucose levels after eating a carbohydrate-rich meal confer benefits to type 2 diabetic and insulin-resistant individuals, and may also help to reduce the risk of developing these chronic diseases. It is widely accepted that the modulation of specific lifestyle factors, such as diet and exercise, can reduce the risk factors associated with type 2 diabetes. Several meta-analyses of data from previous clinical studies have demonstrated that dietary fibre improves the glycaemic response in patients, that is, their blood sugar levels after food consumption.

Several international health and food safety regulators currently authorise the use of health-related claims for some foodstuffs containing specific dietary fibres, stating the benefits of reduced risk of diabetes via enhanced glucose regulation. Yet, irrespective of the renowned benefits and the public awareness of these, typical consumption of fibre falls well below the recommended levels in many countries.

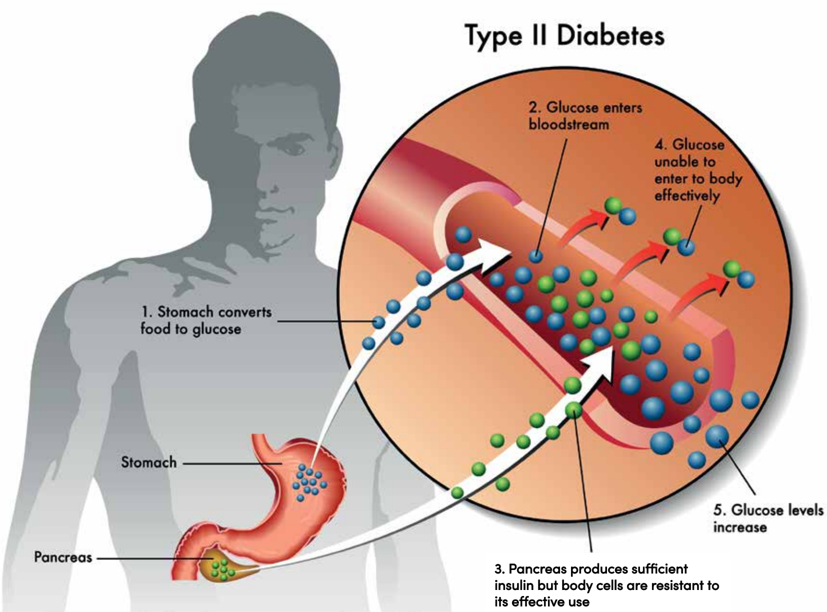
The Cost of Diabetes

The global epidemic of type 2 diabetes comes with significant health and cost implications. The global incidence of diabetes is expected to reach 592 million by 2035, and diabetes is currently responsible for 5.1 million deaths across the world each year. Of particular concern is that over one-quarter of deaths in some groups of south-east Asian women are attributed to diabetes.

The cost to Europe and North America is around 70% of the total annual estimated health costs, somewhere in the range of US$612–1099 billion. Thus, reducing this vast financial burden through lifestyle interventions and effective management and prevention is a major public health priority.

Soluble vs Insoluble Fibre

There are two major classifications of dietary fibre, namely, insoluble or water-soluble. The solubility of fibre is key to what happens to it as it moves through the gut. Insoluble fibre such as plant cellulose and wheat bran support the action of the gut by maintaining faecal bulk, and a portion of insoluble fibre is fermented by gut bacteria.



In contrast, soluble fibres such as gums and pectin produce thick, viscous networks when hydrated in the gut. Soluble fibres are more viscous than insoluble fibres, and differences in viscosity of individual types of soluble fibre in the conditions of the gastrointestinal tract are likely to be a key component in determining their specific biological functions. There are many potential mechanisms by which an increase in the viscosity of gut contents may affect the breakdown of carbohydrates and the uptake of glucose from the intestine.

The viscosity of a soluble dietary fibre depends upon the specific gut conditions. The pH level, water content, and presence of other excreted components (such as bile from the liver), all alter viscosity. A further role is played by the specific structures of the soluble fibres themselves, since their molecular structures can vary widely. Long, linear polymers are able to produce greater viscosities than branched polymers, likely due to the ability of the linear molecules to 'tangle' in solution compared to other structures.

Soluble Fibre and Viscosity

Professor Goff and his colleagues used a two-stage laboratory-based *in vitro* model of digestion to identify the specific gastric and intestinal conditions that alter the viscosity of a range of soluble fibre polymers.

The team found that some of the soluble fibres tested, initially at the same viscosity, resulted in almost no viscosity following simulated digestion in the laboratory, whilst others such as xanthan retained approximately 30–40% of their initial viscosity. Furthermore, the addition of both protein and starch to the test compounds to simulate foodstuffs increased viscosity across the range but did not modify the relative viscosity retention results.

The team concluded from these experiments that viscosity in the conditions of the gastrointestinal tract may be more important in determining the physiological function of soluble fibres and gums rather than the initial viscosity or starting concentration in food or solution.

Plant Starch Digestion in the Presence of Dietary Fibre

Unmodified plant starch, a carbohydrate that is an important energy source, has a granular structure, comprised of polymers of the sugar, D-glucose, linked via one of two chemical bonds, (i) linear amylose or (ii) branched amylopectin.

When eating, the starch polymer breakdown starts in the mouth, where it is acted on by a salivary enzyme, alpha-amylase. Further along the digestive system, in the small intestine, continued digestion occurs via alpha-amylase produced by the pancreas. This breakdown mostly produces the reducing sugars, maltose, maltotriose, and maltotetraose. The sugars are further digested by specific enzymes to produce individual glucose molecules, the end product of starch digestion.

Professor Goff and his team studied the effects of various soluble dietary fibres on the digestion of both native starch granules and pre-gelatinized plant starch. The concentrations of each dietary fibre were substantially different so that the starting viscosities were equivalent. Amylolysis, the enzymic breakdown of starch, was determined by both sample viscosity reduction and the concentration of reducing sugars (such as maltose) that were produced.

Professor Goff and his team found that, as a result of interrupted amylolysis, dietary fibre slows down the rate by which viscosity is reduced and concurrently slows the rate of maltose production. Importantly, they also showed that lowest rates of starch hydrolysis were correlated with highest viscosity retention results. *In vitro* testing showed that reduced amylolysis may be important in the dampening effect on the glycaemic response when dietary fibre is added to starch-rich meals.

They also looked at the ability of these fibres to reduce the diffusion rate of glucose after the breakdown of starch. In humans, diffusion of glucose within the small intestine and subsequent uptake of glucose into the bloodstream are linked to the release of insulin and, therefore, a factor in diabetes management.

From these *in vitro* analyses, the team identified several major outcomes: (i) all of the tested dietary fibres reduced the release and diffusion of glucose from starch, (ii) this correlated with

'intestinal' viscosity, (iii) the effects of the gums were more notable 60 minutes after enzymatic digestion, and (iv) xanthan gum resulted in the greatest modulation (inhibition) of glucose release and diffusion, and also the highest viscosity retention, when compared to control and all other test compounds.

The mechanism by which the dietary fibre components interfere with amylolysis is likely to be the result of reduced diffusion of either enzyme or its target (starch), or by inhibiting effective mixing. Professor Goff's team suggested that the absorption of dietary fibre directly to either enzyme or substrate is less likely to contribute to this process.

Gum-based Dietary Fibres and Control of Glucose Levels

Following on from their *in vitro* laboratory analyses, Professor Goff and his team conducted a controlled human clinical trial to test the efficacy of gum-based dietary fibres in controlling glucose levels following the consumption of pudding products. More specifically, they tested a range of mucilage gums, plant-derived components that can thicken, stabilise, and emulsify foods. These included yellow mustard mucilage, fenugreek gum, and flaxseed mucilage, which allow for excellent incorporation into foods.

Two different pudding products were prepared, using two different carbohydrate sources: tapioca starch or high maltose corn syrup. The fibre concentrations added to the puddings were designed to produce equal viscosity of gut contents after digestion, based on *in vitro* digestion analyses. The team ensured equivalent protein concentrations and removed all fat from the formulations.

Participants consumed a pudding with each dietary fibre, or the no dietary fibre control, on different test days. Participants provided blood samples at intervals between 15 minutes and 2 hours, by which point blood glucose levels were approximately equivalent to pre-eating baseline levels. Peak blood glucose occurred between 30 and 60 minutes.

Results showed that all soluble dietary fibre treatments produced significantly lower blood glucose levels compared to the control treatment at 30 minutes and at 2 hours. Both peak serum concentration of glucose and insulin were significantly lower for all treatments compared to control but there was no significant difference detected among any of the dietary fibre treatments. Starch had slightly less impact on blood glucose compared to maltose whereas gastric emptying rate, as measured by an added marker to the fibre-based puddings and control, had more of an impact.

The three dietary fibre test compounds were provided at concentrations to generate the same levels of viscosity within the small intestine by the addition of different quantities of fibre. However, consuming the varying amounts of dietary fibre resulted in equivalent alterations of blood glucose and insulin compared to control. This highlights the pivotal nature of viscosity in controlling the glycaemic response.

Mechanisms of Action and Rheology of Dietary Fibre

Rheology, the behaviour of non-Newtonian fluids like the viscous gels produced by the dietary fibres being tested, is likely to be significant to understanding the mechanism of action of these fibres in modifying the glycaemic response, and specifically, blood glucose levels and serum insulin levels after the consumption of food.

Professor Goff's team has found that all of the following mechanisms of action are involved in glycaemic control after eating with dietary fibre, and suggest these occur in the following order: (i) delayed emptying of the stomach, (ii) reduced digestive enzyme action in the small intestine, (iii) reduced or inhibited diffusion of the starch fragments or glucose molecules in the small intestine, and (iv) control of gut hormone release, responsible for digestion and absorption. By understanding the specific type of dietary fibre that best controls each action based on its molecular structure, fibre blends for glycaemia control can thus be optimised.

Future Health Benefits

Professor Goff and his colleagues propose that a greater focus on substantiating the health claims of dietary fibre supplemented foodstuffs is needed. They believe that profiling the specific actions and concentrations of individual dietary fibres is critical. To this end, they plan to continue investigating the relationship between the molecular structures and physical behaviour in the gut after consuming soluble dietary fibres. For meaningful health claims, the concentration of each soluble fibre needed to induce a glycaemic response would need to be specified, rather than relying on generalised intake values for all fibres as currently suggested.

Isolated and specific soluble dietary fibre can be consumed directly as a nutraceutical supplement or it can be added to foods during manufacture, to produce functional foods with potential for health claims. The challenge for food manufacturers is to incorporate sufficient soluble fibre per serving of product and not alter the taste and texture of the product, since viscous soluble fibres such as gums can have a significant impact on food quality. This is another area of active research for Professor Goff and his colleagues, with plenty of work left to do.

Meet the researcher

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Professor Douglas Goff is a Professor of Food Science at the University of Guelph in Canada with over three decades of experience in his research field. After completing his PhD at Cornell University, USA, in 1987, Professor Goff returned to the University of Guelph where he had previously completed his undergraduate degree. His research program has since then focussed on ice cream and dairy systems, hydrocolloid functionality in food systems, and polysaccharide structure-function relations. For the last 10 years, he has also examined the relationship between physical and physiological functionality of polysaccharides as a source of dietary fibre. As a renowned scientist, Professor Goff shares his expertise internationally with Ice Cream Technology Industry members. To date, Professor Goff has supervised 60 graduate students and has published two books, 40 book chapters, and 180 refereed journal articles. Furthermore, in 2017, Professor Goff received the prestigious Food Hydrocolloids Trust Medal for lifetime achievement.

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FURTHER READING

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