FOOD & FUNCTION

Impact of dietary fibre-enriched ready-to-eat extruded snacks on the postprandial glycaemic response of non-diabetic patients

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Food intervention is a financially sensible way for prevention and treatment of diabetes. Extruded snack foods are considered high glycaemic products. Our previous research illustrated that postprandial glycaemic responses to snacks are manipulated by altering dietary fibre and starch contents. The current research assessed the effect of psyllium and oat bran on postprandial glycaemia and in vitro digestibility. Addition of psyllium fibre to extruded snack products significantly reduced both the in vitro and in vivo glycaemic responses of products compared to a control snack product recipe. Oat bran inclusion reduced in vitro starch digestibility but not in vivo glycaemic response. The inclusion of oat bran into the snack products appeared to extend the glycaemic response of individuals compared to the control snack, suggesting a possibility of prolonging glucose release and potentially affecting satiety responses. The positive effect in attenuating glucose response means that psyllium fibre could be a target for inclusion by the snack food industry to effectively manipulate postprandial glucose response of individuals.

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Manipulation of glycaemic response to foods through ingredient selection and engineering novel food structures has attracted intense interest recently [1–3]. This has revolved around utilising dietary fibres to regulate the rate and extent of starch degradation (and hence glucose release) in foods [4–7]. Consumer preference for ready-to-eat snack products has led to a preponderance of snack products being available. These snacks are generally cheap, energy dense, but nutrient poor [8, 9]. Most of these snacks are produced using extrusion technology, which in itself can alter the chemical composition and structure of foods to increase the availability of carbohydrates for digestion [10, 11].

In order to counter the anti-nutritive values of extruded snacks, the food industry has attempted to harness the glycaemic modulating potential of dietary fibres [12–14]. Oat bran [15–17] and psyllium [18, 19] are two examples. Researchers have investigated the role of different dietary fibres in model food systems in the modulation of glycaemic response either by hypothesising from in vitro starch digestion methods, or by invasive in vivo glycaemic response trials [20–24]. This study evaluated the potential glycaemic benefits of psyllium and oat products by using both an enzymatic in vitro starch degradation methodology [26] and conventional in vivo glycaemic response procedures in 12 healthy subjects (see Supporting Information).

Psyllium and oat bran were incorporated into a ready-to eat-snack at a 15% replacement concentration to flour (Table S1 – see Supporting Information). The base recipe used in this study had been acquired from a commercial partner [8]. Extruded products were manufactured using a Werner Pfleiderer (Stuttgart, Germany) twin-screw extruder (see Supporting Information for process methodology). Comparisons were made between the response of individuals ($n = 12$) after consuming a standard 25 g glucose drink as well as a product control (recipe without added dietary fibre) against the different dietary fibre treatments. Incremental areas under the blood glucose (in vivo) and glucose release (in vitro) curves were calculated using the trapezoid rule and ignoring area beneath the baseline [27].

Figure 1 illustrates that the in vivo postprandial blood glucose concentrations of the control and oat bran snacks were

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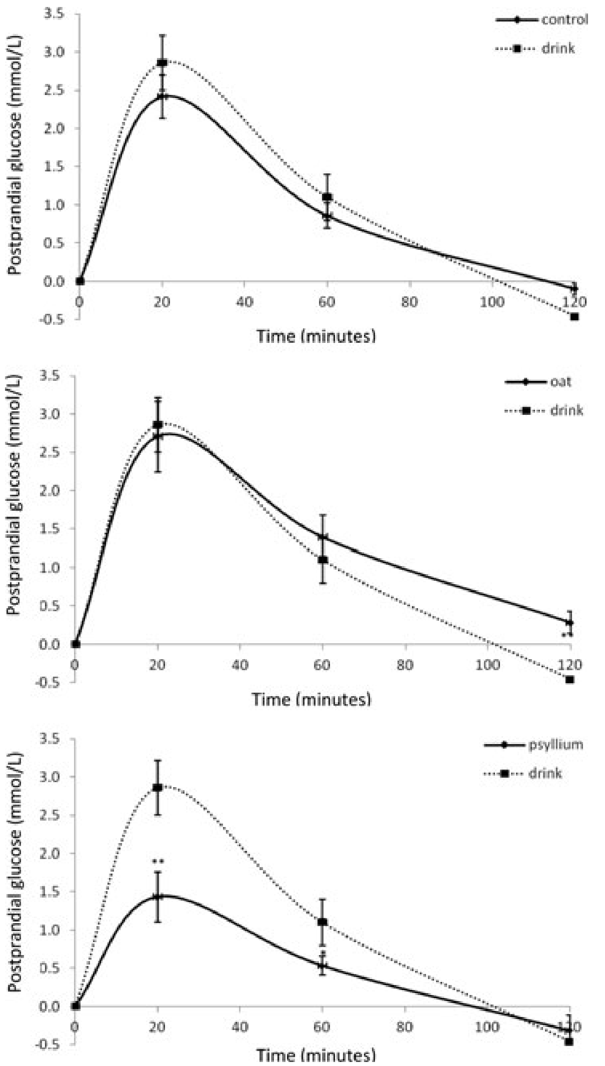

Figure 1. Postprandial blood glucose response curves after consumption of control, oat bran, and psyllium snack products compared with a response after intake of a 25 g glucose drink. Mean ± SEM of 12 individuals. Significances calculated using a multi-sample *t*-test (*$p < 0.05$, **$p < 0.005$).

similar to the glucose drink at 20 min. However, psyllium snacks reduced the blood glucose value compared to glucose drink ($p \leq 0.005$), and both oat bran or control snacks ($p \leq 0.05$). Similarly, postprandial glucose at 60 min for the control, oat bran snacks, and glucose drink were similar, whereas the postprandial glucose values of psyllium were lower than the other treatments. Oat bran snacks produced a shallower gradient between 20 and 60 min than the other samples in the study. Predictive glucose release using in vitro methodology (Fig. 2) showed that all snack products were significantly different to each other at each sample time ($p \leq 0.05$). The order of the in vitro glucose response of the snacks was control > oat bran > psyllium.

Table 1. Average incremental area under the curve values (iAUC) for extruded samples as determined using both the in vivo (n = 12) and in vitro (n = 2) procedures. Values represent means ± SEM.

Sample	In vivo mmol glucose/L blood	In vitro mg glucose/g food
Control	112.42 ± 14.97^{a}	573.71 ± 3.21^{a}
Oat bran	159.33 ± 27.60^{a}	542.22 ± 1.42^{b}
Psyllium	62.92 ± 13.10^{b}	478.63 ± 0.28^{c}
Glucose	151.30 ± 18.75^{a}	-

Values with the same superscript letter assigned to them are not significantly different ($p \leq 0.05$).

The iAUC values obtained both in vivo and in vitro are presented in Table 1. The in vivo psyllium iAUC response was lower than the control snack ($p \leq 0.05$), oat bran snack, and glucose drink ($p \leq 0.05$). In contrast, the in vitro iAUC responses for all samples were significantly different from each other ($p \leq 0.05$). The in vitro iAUC values for the psyllium snack product were consistently lower than the other treatments ($p \leq 0.05$).

Several researchers have attempted to investigate the in vivo response of individuals consuming oat bran-rich food products [28–30]. Oat bran can contribute to lowering the glycaemic impact of foods through the effect of β-glucans contained in oat bran altering the rheological nature of food digesta [29]. Other researchers have explained reductions in glycaemic responses of individuals after ingestion of dietary fibres through viscosity-related properties inhibiting starch degradation [4, 18, 30].

Both psyllium and oat bran snacks reduced in vitro digestion compared with the control. The addition of psyllium fibre to the snack products resulted in a greater than 15% reduction of glucose production over 120 min compared to the control snack. Addition of oat bran to the snack products resulted in a 5.4% glucose reduction. Similar results have been obtained by a number of researchers investigating dietary fibres, with authors explaining the effect of dietary fibre in reducing starch degradation on the possibility of dietary fibres coating starch granules and inhibiting enzyme penetration [1, 4, 13, 16, 18] and the possibility that the viscous nature of dietary fibres affects the efficiency of enzyme functionality [5, 7, 31].

The lower blood glucose iAUC (in vivo) of psyllium snacks compared with the control snack, oat bran snack, and glucose drink may be related to the manner in which dietary fibre reduces glucose release either through binding the starch to prevent amylolytic degradation or by altering the overall viscosity of the digesta limiting water mobility and hence enzyme accessibility [4, 8, 17]. The blood glucose concentration induced by the oat bran snack did not fall back to the fasting blood glucose within the 2 h of the experiment. This is an interesting observation suggesting that the oat bran may have a role in slowing the overall digestion rate of starch and thus manipulating the glucose release rate. This is in line

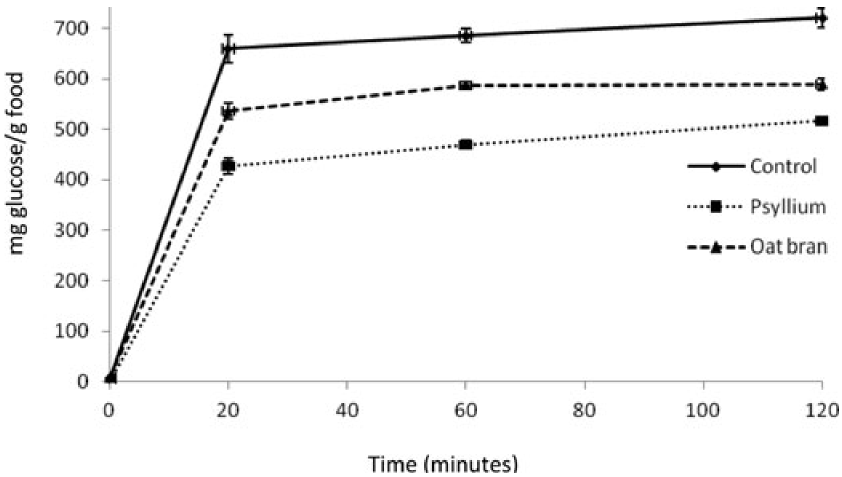

Figure 2. In vitro digestion of extruded snack products glucose produced (mg) per gram of food. Mean ± SEM of 12 individuals. All values were significantly different from each other ($p < 0.05$).

with previous researchers studying a range of dietary fibres in foods [1, 8, 24, 29].

It was not possible to correlate the results obtained through in vivo determination with those obtained through in vitro determinations of glucose response. The inability to show similar trends for both dietary fibres used may be due to inherent person-to-person variation in postprandial responses. Alternatively, there could be a significant contribution occurring in relation to the effect of the extrusion process on the state of dietary fibres as presented to in vivo digesta. This in turn may regulate the absorption of glucose postprandially.

To conclude, the research clearly indicates that the use of psyllium fibre in extruded snack products at 15% level of inclusion can significantly reduce the overall postprandial glucose response. A reduction of glucose response against the control product of over 16% was observed in using the in vitro analysis method, whereas a reduction of 43% was observed using in vivo methodology. These results indicate that there is a potential utilisation of psyllium fibre in reducing the glucose response of extruded products.

The authors have declared no conflict of interest.

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