Eur J Nutr (2009) 48:395–402
DOI 10.1007/s00394-009-0026-x

ORIGINAL CONTRIBUTION

The influence of dietary fibre source and gender on the postprandial glucose and lipid response in healthy subjects

Matilda Ulmius · Anna Johansson · Gunilla Önning

Received: 9 February 2009 / Accepted: 21 April 2009 / Published online: 5 May 2009

Abstract
Background Consumption of soluble dietary fibre is correlated with decreased postprandial glucose and insulin responses and hence has beneficial effects on the metabolic syndrome.
Aim of the study To investigate the effects on postprandial glucose, insulin and triglyceride concentrations of meals enriched with soluble dietary fibres from oats, rye bran, sugar beet fibre or a mixture of these three fibres.
Methods Thirteen healthy human volunteers (6 men and 7 women, aged 20–28 years) were included in the study. The subjects came to the study centre once a week after an overnight fast to ingest test meals and a control meal in random order. The meals contained either oat powder (62 g, of which 2.7 soluble fibre), rye bran (31 g, of which 1.7 g soluble fibre), sugar beet fibre (19 g, of which 5 g soluble fibre), a mixture of these three fibres (74 g, of which 1.7 g soluble fibre from each source, giving 5 g soluble fibre) or no added fibre (control) and were all adjusted to contain the same total amount of available carbohydrates. Blood samples were drawn before and every 30 min up to 180 min after the meals.
Results Meals with rye bran gave a lower postprandial glucose peak when compared with the control meal, and this effect was more pronounced in women compared to men. Oat powder, containing a low amount of total fibre and a high amount of carbohydrates in liquid matrix, gave a higher incremental glucose peak concentration compared to rye bran and sugar beet fibre and higher insulin incremental area under curve compared to control. The oat powder also influenced the effects of the mixed meal, diminishing the glucose-lowering effects. Postprandial triglyceride levels tended to be higher after all fibre-rich meals, but only significant for oat powder and the mixed meal when compared with the control meal.
Conclusions Postprandial glucose, insulin and triglyceride concentrations are influenced by dietary fibre-rich meals, depending on fibre source, dose of soluble and total fibre and possibly gender.

Keywords Oats · Rye · Sugar beet fibre · Glucose · Insulin · Triglyceride · Gender

M. Ulmius · A. Johansson · G. Önning (✉)
Biomedical Nutrition, Pure and Applied Biochemistry,
Centre for Chemistry and Chemical Engineering,
Lund University, P.O. Box 124, 221 00 Lund, Sweden
e-mail: gunilla.onning@tbiokem.lth.se

M. Ulmius
e-mail: matilda.ulmius@tbiokem.lth.se

A. Johansson
e-mail: anna.johansson@tbiokem.lth.se

Introduction

The prevalence of obesity and insulin resistance appear to increase in the European population, and they are two important components of the metabolic syndrome [29]. These metabolic abnormalities increase the risk of type 2-diabetes and cardiovascular disease [10, 11]. An increased intake of dietary fibre has beneficial effects on and can prevent several elements of the metabolic syndrome and this is related to the fibre source, chemical structure and physical properties [8, 19]. For example, beverages rich in dietary fibre have been shown to lower postprandial glucose and insulin response [2].

Dietary fibres are divided into soluble and insoluble fibres. Such a classification is unclear, however, since the same fibre can be both soluble and insoluble, depending on its physicochemical properties and the environment.

Soluble fibres produce viscous solutions and in the intestine the increased viscosity may reduce the rate of digestion and absorption of macronutrients, including carbohydrates and fat. Consumption of soluble fibres has been correlated with lower postprandial glucose and insulin responses [3]. Intake of insoluble fibres and whole grain foods has been associated with improved insulin sensitivity [26]. The structure of the insoluble fibres may also hinder the access of enzymes to substrates and diminish the rate of micronutrient digestion and absorption. Common diets include a mixture of soluble and insoluble fibres and most probably result in a combination of these effects.

The main soluble fibre in oats is β-glucan [16], while sugar beet fibre is rich in pectin [20] and rye contains arabinoxylan [22]. All these fibre sources have been shown to reduce glucose and insulin responses in meal studies with healthy subjects [1, 12, 24]. Soluble dietary fibre from oats or barley has approval for health claims by the Food and Drug Administration in the US [6], claiming that consumption of oats or barley products containing 3 g of β-glucan per day may lower the risk of heart disease. To qualify for the claim the food product must contain 0.75 g of β-glucan per serving.

Few studies have compared the effects of different soluble fibre sources on postprandial responses and hardly any study the effects of fibre mixtures in the same meal, even though this is more similar to regular eating habits. The aim of present study was to investigate the postprandial glucose, insulin and triglyceride responses in healthy subjects after intake of meals containing soluble fibres from oats, rye bran, sugar beet fibre or a meal containing a mixture of these three fibres.

Subject and methods

Study design

Five different breakfast meals were served in a randomised and single-blinded manner once a week, containing either spray dried oat drink ("oat powder"), rye bran, sugar beet fibre, a mixture of all three fibre types or a control meal without added fibres. Venous blood samples were collected before and every 30 min after the meal for 180 min. Samples were analysed for glucose, insulin and triglyceride concentrations. An ethical approval of the study was given by the Regional Ethical Review Board in Lund, Sweden (No. 98/2007) and the subjects gave a written consent before inclusion in the study.

Subjects

A total of 18 healthy volunteers, 10 men and 8 women, were recruited by advertisement among university employees and students. The inclusion criteria were 20–65 years of age with body mass index (BMI) 18–30 kg/m^2. Individuals were excluded if they reported pregnancy or breastfeeding, diabetes mellitus, hepatitis B, use of blood lipid lowering pharmaceuticals or intolerance or allergy to cereals or sugar beet fibre. Subjects were asked to avoid intense physical activity, alcohol, pain relief tablets or nutritional supplements the day before each trial day. They were instructed not to eat or drink after 7 p.m., except tap water and the supplied white bread of which they should eat an optional amount at 9–10 p.m., the same amount before each trial day. Use of tobacco was not allowed on the trial day and the subjects were told to travel by bus or walk slowly to avoid extra physical activity. The test meals were ingested at the study centre in the trial day morning between 6.45 and 8.30 a.m. according to a schedule.

Study products

Oat powder, rye bran and sugar beet fibre were supplied by Oatly AB (Landskrona, Sweden), Lantmännen Food R&D (Järna, Sweden) and Danisco Sugar AB/Fibrex (Copenhagen, Denmark), respectively. Rye bran was milled to <800 µm particle size (Perten Laboratory Mill 120, Perten Instruments AB, Huddinge, Sweden), whereas oat powder and sugar beet fibre had particle sizes of 20–50 and <125 µm, respectively, according to the producers. Nutrient content of the fibres was analysed by Eurofins (Eurofins Food & Agro AB, Lidköping, Sweden). The different fibre preparations were mixed with a blackcurrant beverage with pulp ("Harvest of the year", Kiviks musteri AB, Kivik, Sweden) with a serving size of 250 ml. The aim was to include 5 g soluble fibre in each fibre meal, but due to high carbohydrate content in the oat powder and a high insoluble fibre content in the rye bran, these meals had a lower soluble fibre content (2.7 and 1.7 g, respectively). The addition of rapeseed oil (Zeta, Di Luca & Di Luca AB, Stockholm, Sweden) was used to balance the total amount of lipids, while dextrose powder (Dextropur, Dextro Energy GmbH & Co. KG, Krefeld, Germany) and white wheat bread (Lockarps bageri, Malmö, Sweden) were used to balance the amount of total carbohydrates in the meals (Table 1). Dextrose powder was used in meals where the added fibre contained low amount of carbohydrates to make the amount of bread reasonable to ingest. All meals contained 75 g available carbohydrates and 7.9 g lipids while the protein content varied between 5.4 and 10 g, since it was not possible to find a neutral plant protein to add. A glass of 200 ml tap water was served together with the beverage and bread, and the subjects were instructed to ingest the breakfast within 15 min. Every trial day, the subjects had to report any illness and at the end of the total study period they were given a questionnaire to record any

Table 1 Standardised breakfast meals

	Amount (g)	Energy (kJ)	Carbohydrate (g)	Lipids (g)	Protein (g)	Soluble fibre (g)	Total fibre (g)
Control meal							
Beverage	250.0	500	30.0	–	–	–	–
White bread	67.7	768	35.9	2.0	5.4	0.3	1.4
Dextrose	10.0	155	9.1	–	–	–	–
Rapeseed oil	5.9	218	–	5.9	–	–	–
Total (% of total meal energy)	333.6	1,641	75.0 (77)	7.9 (18)	5.4 (5)	0.3	1.4
Oat powder meal							
Oat powder	61.7	1,009	45.0	3.7	6.3	2.7	3.3
Beverage	250.0	500	30.0	–	–	–	–
Rapeseed oil	4.2	156	–	4.2	–	–	–
Total (% of total meal energy)	315.9	1,665	75.0 (76)	7.9 (18)	6.3 (6)	2.7	3.3
Rye bran meal							
Rye bran	30.6	276	8.6	1.5	4.4	1.7	12.0
Beverage	250.0	500	30.0	–	–	–	–
Dextrose	10.0	155	9.1	–	–	–	–
White bread	51.5	583	27.3	1.5	4.1	0.3	1.0
Rapeseed oil	4.9	181	–	4.9	–	–	–
Total (% of total meal energy)	347.0	1,695	75.0 (74)	7.9 (18)	8.5 (8)	2.0	13.0
Sugar beet fibre meal							
Sugar beet fibre	18.7	94	2.5	0.6	1.7	5.0	11.9
Beverage	250.0	500	30.0	–	–	–	–
Dextrose	10.0	155	9.1	–	–	–	–
White bread	63.0	714	33.4	1.9	5.0	0.3	1.3
Rapeseed oil	5.4	201	–	5.4	–	–	–
Total (% of total meal energy)	347.1	1,664	75.0 (75)	7.9 (18)	6.7 (7)	5.3	13.2
Mixture meal							
Oat powder	37.9	619	27.6	2.3	3.9	1.7	2.1
Rye bran	30.3	274	8.6	1.5	4.3	1.7	11.9
Sugar beet fibre	6.2	31	0.8	0.2	0.6	1.7	4.0
Beverage	250.0	500	30.0	–	–	–	–
White bread	15.1	171	8.0	0.4	1.2	0.1	0.3
Rapeseed oil	3.5	130	–	3.5	–	–	–
Total (% of total meal energy)	343.0	1,725	75.0 (73)	7.9 (17)	10.0 (10)	5.2	18.3

Nutrient contents were calculated according to the declared nutrient content, except for the dietary fibres that were analysed separately

side effects related to the study products. None of the subjects reported gastrointestinal discomfort during the trial despite the high quantity of dietary fibre in some of the meals.

Blood sampling and analysis

The subjects ate the test meals at the study centre after an overnight fast. A catheter was inserted into an anterior forearm vein for venous blood sampling before and at 30, 60, 90, 120, 150 and 180 min after the meal. Blood sampled in EDTA tubes was immediately analysed for plasma glucose by a glucose-oxidase based method (HemoCue® AB, Ängelholm, Sweden). The remaining blood was left on a platform (35 rev/min, platform STR 8, Stuart Scientific Co., Stone Staffordshire, UK) before swing-out centrifugation (10 min, 2,200*g*, at room temperature, Beckman GPR, Beckman Coulter Inc., Fullerton, CA, USA) to separate plasma. The plasma was stored in a refrigerator for up to 2 days until delivery at Lund University Hospital for accredited analysis of triglycerides using Hitachi Modular-P4 equipment. For the measurement of serum insulin, whole blood was left to clot on the platform for maximum 60 min followed by swing-out centrifugation (20 min, 3,200*g*, room temperature). The serum was stored at −20°C until analysis by an enzymelinked immunosorbent assay (Human Insulin ELISA-kit, Mercodia AB, Uppsala, Sweden).

Calculations and statistical analysis

The primary endpoint for the present study was to examine the effects of dietary fibres on postprandial glucose concentration. Glucose and insulin incremental areas under the curve (IAUC) were calculated geometrically applying the trapezoid rule [4, 5]. General characteristics are reported as means and standard deviation (SD) whereas all other data are presented as means and standard error of the mean (SEM). Statistical analyses were performed in SPSS 16.0 (SPSS Inc., Chicago, IL, USA) using the Friedman test to explore differences between the effects of different meals at each time point. If significance was found, the Wilcoxon signed rank test was run for pairwise evaluations. The Mann–Whitney *U* test was used to evaluate any differences in response between genders. A *p* value of <0.05 was considered significant in all analyses.

Results

Subjects

In total, 18 subjects were included in the study of which 14 (6 men and 8 women) completed the 5-week protocol. Four subjects dropped out; three for personal reasons and one because of illness not related to the study. One woman was excluded due to illness and low compliance on one of the trial days. Baseline characteristics of the 13 subjects who were included in all calculations are presented in Table 2.

Effects on glucose concentration

Peak glucose concentrations were detected at 30 min after breakfast, regardless of the dietary fibre source (Fig. 1). Rye bran gave a significantly 35% lower incremental glucose peak concentration compared to the control (Table 3). Sugar beet fibre, oat powder and the mixture resulted in reduced incremental glucose peak concentrations compared to the control; however, not statistically significant. In addition, the rye bran and sugar beet fibre meals gave significantly lower incremental peak glucose response compared to oat powder (31 and 28%, respectively). There were no significant differences in glucose IAUC between any of the meals. However, the meals containing sugar beet fibre and rye bran tended to give a reduced glucose IAUC compared to control, while the mixed meal was more similar to control and the oat powder meal resulted in a slightly increased IAUC.

A post hoc analysis separating postprandial incremental glucose concentration and IAUC for men and women was calculated (Table 3). For all fibre intakes, the incremental glucose concentration was lower for women than for men, with significant differences for rye bran and the mixed meal at 30 min. The women had significantly lower

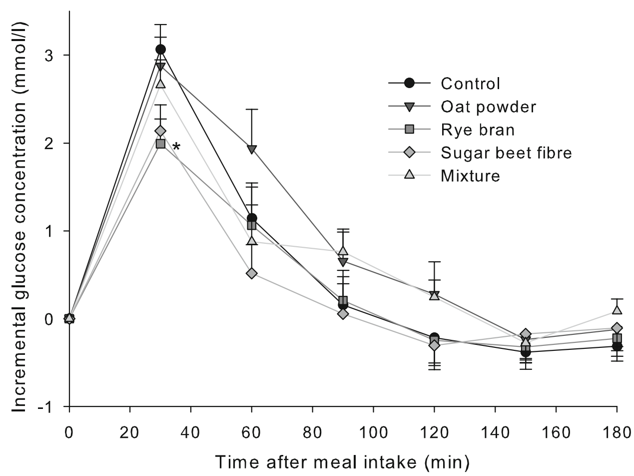

Fig. 1 Incremental blood glucose responses in healthy humans after ingestion of meals containing different fibre sources ($n = 13$, means and SEM). *Asterisk* represents Wilcoxon signed rank test; significantly different compared to control ($p < 0.05$)

Table 2 Baseline characteristics of subjects, $n = 13$ (men $n = 6$, women $n = 7$)

	Mean (SD)	Range	Mean men (SD)	Mean women (SD)
Age (years)	22.6 (2.3)	20–28	23.5 (2.9)	21.9 (1.6)
Height (m)	1.73 (0.08)	1.60–1.89	1.77 (0.10)	1.70 (0.03)
Weight (kg)	69.5 (11.7)	57–94	76.5 (12.8)[b]	63.4 (6.9)
Body mass index (kg/m^2)	22.9 (2.2)	20.1–26.6	24.2 (2.0)	21.9 (1.9)
Fasting glucose (mmol/l)	5.2 (0.3)	4.4–6.3[a]	5.5 (0.3)[b]	5.1 (0.2)
Fasting insulin (mU/l)	5.1 (2.0)	0.9–11.7	4.2 (1.7)	5.9 (1.9)
Fasting triglycerides (mmol/l)	1.1 (0.5)	0.61–3.61	1.2 (0.7)	1.0 (0.3)

[a] 6.3 mmol/l from subject who reported a common cold

[b] Mann–Whitney *U* test; significantly different compared to mean values for women ($p < 0.05$)

Table 3 Fasting glucose, incremental peak glucose concentrations and glucose incremental area under the curve (IAUC) in healthy humans after the intake of meals containing different fibre sources

	Fasting (mmol/l)	Δ30 min (mmol/l)			IAUC 0–120 min (mmol min/l)		
		All	Men	Women	All	Men	Women
Control	5.2 (0.1)	3.1 (0.3)	3.4 (0.4)	2.8 (0.4)	159.3 (22.9)	158.5 (29.5)	159.9 (36.5)
Oat powder	5.1 (0.2)	2.9 (0.3)	3.5 (0.5)	2.3 (0.4)	173.1 (33.0)	224.2 (65.5)[c]	129.4 (16.9)
Rye bran	5.4 (0.1)	2.0 (0.3)[a,b]	2.7 (0.4)[c]	1.4 (0.2)	113.2 (27.5)	188.9 (41.3)[c]	48.3 (8.5)
Sugar beet fibre	5.3 (0.1)	2.1 (0.3)[b]	2.5 (0.4)	1.8 (0.4)	102.2 (21.7)	134.9 (38.1)	74.3 (20.9)
Mixture	5.2 (0.1)	2.7 (0.3)	3.4 (0.3)[c]	2.0 (0.2)	143.0 (24.3)	198.0 (30.1)[c]	95.8 (27.4)

Values are means and SEM; $n = 13$ (men $n = 6$, women $n = 7$)

[a] Wilcoxon signed rank test; significantly different compared to control ($p < 0.05$)

[b] Wilcoxon signed rank test; significantly different compared to oat powder ($p < 0.05$)

[c] Mann–Whitney U test; significantly different compared to women ($p < 0.05$)

glucose IAUC using the 0–120 min interval compared to the men for oat powder, rye bran and the mixed meal.

Effects on insulin concentration

The highest insulin concentrations were detected 30 min after breakfast. No significant differences in incremental concentrations were observed for any of the test meals compared to the control. However, the oat powder meal gave a significantly higher incremental insulin response compared to rye bran, sugar beet fibre and the mixed meal at 60 min (Table 4). The insulin IAUC for meals with sugar beet fibre and rye bran was somewhat lower using the 0–120 min interval compared to the control meal, although not significantly. The largest insulin IAUC was observed for the oat powder meal with significant differences compared to control, rye bran and sugar beet fibre meal for all time intervals (Table 4). There were no statistically significant differences for incremental insulin responses or insulin IAUC when comparing men and women.

Effects on triglyceride concentration

The postprandial incremental triglyceride concentrations tended to be higher after the fibre meals compared to the control meal, but only significant for oat powder and the mixed meal at 60 min (Fig. 2). There were no differences in incremental triglyceride response between men and women.

Discussion

The study shows that meals containing soluble dietary fibre, and in particular those also containing insoluble fibres, have effects on postprandial glucose, insulin and triglyceride levels in healthy subjects. A meal containing rye bran significantly lowered incremental postprandial peak glucose compared to control. Furthermore, meals with rye bran or sugar beet fibre resulted in significantly lower incremental peak glucose than the oat powder meal. These two meals also showed significantly lower incremental

Table 4 Fasting insulin, incremental insulin concentrations at 30 and 60 min and insulin incremental area under the curve (IAUC) in healthy humans after the intake of meals containing different fibre sources

	Fasting (mU/l)	Δ30 min (mU/l)	Δ60 min (mU/l)	IAUC (mU min/l)		
				0–60 min	0–90 min	0–120 min
Control	5.7 (0.4)	39.0 (5.4)	34.2 (5.2)	1,683 (200)	2,458 (309)	2,890 (402)
Oat powder	4.9 (0.6)	51.6 (7.6)	43.8 (3.9)	2,204 (235)[a]	3,227 (285)[a]	3,887 (362)[a]
Rye bran	4.9 (0.7)	38.0 (4.5)	26.5 (4.6)[b]	1,538 (190)[b]	2,212 (271)[b]	2,671 (298)[b]
Sugar beet fibre	4.6 (0.8)	42.8 (7.2)	22.3 (3.4)[b]	1,620 (244)[b]	2,209 (317)[b]	2,596 (377)[b]
Mixture	5.4 (0.9)	48.3 (6.9)	30.1 (5.6)[b]	1,901 (276)	2,736 (420)	3,320 (519)

Values are means and SEM; $n = 13$

[a] Wilcoxon signed rank test; significant different compared to control ($p < 0.01$)

[b] Wilcoxon signed rank test; significant different compared to oat powder ($p < 0.05$)

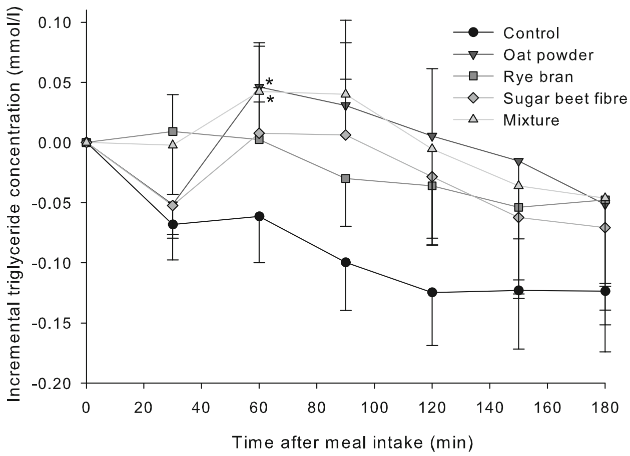

Fig. 2 Incremental triglyceride responses in healthy humans after ingestion of breakfasts containing different dietary fibre sources ($n = 13$, means and SEM). *Asterisk* represents Wilcoxon signed rank test; significantly different compared to control ($p < 0.05$)

insulin concentrations at 60 min and for all IAUC time intervals compared to the oat powder meal.

The finding that the lowest amount of soluble fibre in a meal (1.7 g from rye bran) resulted in the most prominent effect supports the importance of the type of soluble fibre; i.e. arabinoxylan from rye compared to pectin (5 g soluble fibre from sugar beet) or β-glucan (2.7 g soluble fibre from oat). Furthermore, the content of insoluble fibres varied between the fibre sources and appeared to be very important for the postprandial response. The meals with rye bran or sugar beet fibre both contained 12 g of total fibre, while the oat powder meal only contained 3.3 g. A meal with oat bran was also tested, which will be reported separately linked to a transcriptomic analysis.

The oat powder had a lower content of total fibre but a high concentration of carbohydrates and any addition of white bread (or dextrose) was not required in this case as in the other meals. Therefore, all carbohydrates in the oat powder meal were ingested from the beverage. In the study by Biorklund et al. [2], effects on postprandial glucose and insulin levels from oat powder (i.e. mostly soluble fibres) with 5 g of β-glucan was observed, while in a recent study by Granfeldt et al. [9] oat bran flakes (i.e. both soluble and insoluble fibres) with 3 g β-glucan only gave a small reducing effect on postprandial glucose and insulin levels, while 4 g gave a larger effect. The present study demonstrated that 3 g β-glucan in oat powder (soluble fibres) did not lower the postprandial glucose and insulin response, probably due to the low fibre content and the high level of carbohydrates in the liquid matrix.

In addition to the separate fibres, a mixture with all three fibre sources was prepared in one meal to test a meal more similar to regular eating habits, containing 1.7 g of each of the soluble fibre types and 18 g of total fibre. The postprandial response had some resemblance with the effects from the separate components. After a high postprandial glucose peak, similar to the one caused by oat powder alone, the decrease in glucose was slow, presumably due to the contents of rye bran and sugar beet fibre. Although the mixture contained as much soluble rye bran fibre as the rye bran meal alone (1.7 g), and as much total soluble fibre as the sugar beet meal alone (5 g), the presence of oat powder seemed to have a counteracting influence.

In the present study, the meals with oats had a tendency to increase insulin responses compared to control while the glucose responses were similar to the control. This inconsistency between glucose and insulin responses from oat has been shown before [7, 15]. Oats are known to contain high contents of protein [14], and both meals with oats had higher protein content from the added fibre preparations than the other meals. Food proteins give different effects depending on the combination of amino acids, i.e. branched-chain amino acids are suggested to stimulate secretion of insulin and possibly induce insulin resistance. In a study by Nilsson et al. [18] on whey from milk, a positive correlation was found between high insulin levels and the presence of certain amino acids, primarily leucine, isoleucine, valine, lysine and threonine, in the blood samples. Such high insulin levels were also found when whey was replaced by a drink with the five amino acids [18]. Determination of the amino acid composition of each fibre source in present study (data from Danisco Sugar AB/Fibrex and the USDA Nutrient Database [25]) showed that the meals containing oats had a high content of the branched-chain amino acids leucine and valine (isoleucine not determined), but also of arginine, proline and phenylalanine. This finding might explain the increased insulin response after the oat-containing meals but further studies are needed to confirm the hypothesis.

The responses in plasma triglycerides showed that fibre meals tended to give higher incremental responses than the control. Similar results have been observed previously by Redard et al. [23] who gave their subjects test meals with a higher dose of dietary fibre (15 g). They suggested that a decreased digestion and absorption of macronutrients from viscous dietary fibre resulted in a lowered insulin secretion and slower clearance of glucose and triglycerides from the plasma. This suggestion does not explain present results for oat powder that tended to give a high postprandial triglyceride simultaneously with high insulin and glucose responses, maybe due to the low fibre content as discussed previously.

Rye bran was milled to make it more comparable in particle size to the other fibre types, since more soluble fibres can be released from small particles [17]. One reason for the varying effects in postprandial responses might be that rye bran was not processed, while both oat powder and sugar beet fibre had been heat treated. Soluble fibres are sensitive to processing, e.g. with high temperature or extreme pH, which may degrade the structure and diminish the viscous property and thereby the physiological activity [19]. Using beverages as a liquid matrix for the meals is a simple way to serve fibres without extra heating or freezing, and earlier studies have shown postprandial effects when fibre was served in beverages [2, 24]. However, contradictory results were found in a recent study [21] where subjects were provided with 6 g extracted β-glucan from barley mixed either with jam on bread in a food matrix or in a beverage as a liquid matrix. Postprandial glucose and insulin responses were only decreased when fibres were added to the food matrix. Unfortunately, the food matrix had a very different fat and protein content, compared to the beverage, which might have influenced the results. To be physiologically active, the soluble fibres must be able to get hydrated and form viscous gels, and the hydration and viscosity are influenced by the choice of food matrix as well as by processing.

Some trials included either men or women in meal studies, arguing that meal sizes have to be different since men and women may differ in physiological response to nutrients [13, 30]. Other studies, including subjects of both genders, have either not assessed for any differences or reported no differences between genders [12]. A post hoc analysis in the present study showed that women tended to have a lower incremental glucose peak and IAUC after intake of the fibre-rich meals compared to men, but due to a small cohort these results are preliminary. The women had lower BMI than men, but no correlation was found between glucose responses and BMI values. There may be other reasons for the different gender responses, such as relative amount of body fat [27]. The recommended consumption of fibres from FDA regarding health claims for oat and barley products are the same for both men and women. According to the present results, it is important to evaluate gender differences and discuss if these recommendations should be different for men and women, and based on energy intake like other recommendations regarding fibre intake [28].

In conclusion, this study demonstrates that postprandial glucose, insulin and triglycerides are influenced by dietary fibre-rich meals, depending on fibre source, mixture of fibres, dose of soluble and total fibre, fibre processing and possibly gender. However, more studies are needed to evaluate the effects of different doses of each soluble fibre required for beneficial effects and if different doses should be recommended for men and women.

Acknowledgments We thank RN Ingrid Palmquist for performing the blood sampling and Ph.D. Karin Berger for allowing us to use the equipment for insulin analysis. This work has been carried out by financial support from The Swedish Governmental Agency for Innovation Systems (VINNOVA, project 2004-02285).

References

1. Alminger M, Eklund-Jonsson C (2008) Whole-grain cereal products based on a high-fibre barley or oat genotype lower postprandial glucose and insulin responses in healthy humans. Eur J Nutr 47:294–300
2. Biorklund M, van Rees A, Mensink RP, Onning G (2005) Changes in serum lipids and postprandial glucose and insulin concentrations after consumption of beverages with beta-glucans from oats or barley: a randomised dose-controlled trial. Eur J Clin Nutr 59:1272–1281
3. Brennan CS (2005) Dietary fibre, glycaemic response, and diabetes. Mol Nutr Food Res 49:560–570
4. Brouns F, Bjorck I, Frayn KN, Gibbs AL, Lang V, Slama G, Wolever TMS (2005) Glycaemic index methodology. Nutr Res Rev 18:145–171
5. FAO/WHO (1998) Carbohydrates in human nutrition: report of a joint FAO/WHO expert consultation. FAO Food Nutr Pap 66:1–140
6. FDA (2008) A food labeling guide, XI. Appendix C: health claims. In: Requirements for health claims made in labeling. U.S. Food and Drug Administration, CFSAN/Office of Nutrition, Labeling, and Dietary Supplements
7. Flint A, Moller BK, Raben A, Pedersen D, Tetens I, Holst JJ, Astrup A (2004) The use of glycaemic index tables to predict glycaemic index of composite breakfast meals. Br J Nutr 91:979–989
8. Galisteo M, Duarte J, Zarzuelo A (2008) Effects of dietary fibers on disturbances clustered in the metabolic syndrome. J Nutr Biochem 19:71–84
9. Granfeldt Y, Nyberg L, Bjorck I (2008) Muesli with 4 g oat beta-glucans lowers glucose and insulin responses after a bread meal in healthy subjects. Eur J Clin Nutr 62:600–607
10. Grundy SM, Brewer HB Jr, Cleeman JI, Smith SC Jr, Lenfant C (2004) Definition of metabolic syndrome: Report of the National Heart, Lung, and Blood Institute/American Heart Association conference on scientific issues related to definition. Circulation 109:433–438
11. Isomaa B, Almgren P, Tuomi T, Forsen B, Lahti K, Nissen M, Taskinen MR, Groop L (2001) Cardiovascular morbidity and mortality associated with the metabolic syndrome. Diabetes Care 24:683–689
12. Juntunen KS, Niskanen LK, Liukkonen KH, Poutanen KS, Holst JJ, Mykkanen HM (2002) Postprandial glucose, insulin, and incretin responses to grain products in healthy subjects. Am J Clin Nutr 75:254–262
13. Keogh JB, Lau CW, Noakes M, Bowen J, Clifton PM (2007) Effects of meals with high soluble fibre, high amylose barley variant on glucose, insulin, satiety and thermic effect of food in healthy lean women. Eur J Clin Nustr 61:597–604
14. Lockhart HB, Hurt HD (1986) Nutrition of Oats. In: Webster FH (ed) Oats: chemistry and technology. American Association of Cereal Chemists, St Paul, pp 298–300
15. Makelainen H, Anttila H, Sihvonen J, Hietanen RM, Tahvonen R, Salminen E, Mikola M, Sontag-Strohm T (2007) The effect of beta-glucan on the glycemic and insulin index. Eur J Clin Nutr 61:779–785
16. Malkki Y (2001) Oat fiber: production, composition, physio-chemical properties, physiological effects, safety, and food applications. In: Cho SS, Dreher ML (eds) Handbook of dietary fiber. Marcel Dekker, New York, pp 497–517

17. Malkki Y, Virtanen E (2001) Gastrointestinal effects of oat bran and oat gum—a review. Lebensm wiss u Technol 34:337–347
18. Nilsson M, Holst JJ, Bjorck IM (2007) Metabolic effects of amino acid mixtures and whey protein in healthy subjects: studies using glucose-equivalent drinks. Am J Clin Nutr 85:996–1004
19. Onning G (2004) The use of cereal beta-glucans to control diabetes and cardiovascular disease. In: Arnoldi A (ed) Functional foods, cardiovascular disease and diabetes. Woodhead Publishing Ltd., Cambridge, pp 402–421
20. Phatak L, Chang KC, Brown G (1988) Isolation and characterization of pectin in sugar-beet pulp. J Food Chem 53:830–833
21. Poppitt SD, van Drunen JD, McGill AT, Mulvey TB, Leahy FE (2007) Supplementation of a high-carbohydrate breakfast with barley beta-glucan improves postprandial glycaemic response for meals but not beverages. Asia Pac J Clin Nutr 16:16–24
22. Ragaee SM, Campbell GL, Scoles GJ, McLeod JG, Tyler RT (2001) Studies on rye (*Secale cereale* L.) lines exhibiting a range of extract viscosities. 1. Composition, molecular weight distribution of water extracts, and biochemical characteristics of purified water-extractable arabinoxylan. J Agric Food Chem 49:2437–2445
23. Redard CL, Davis PA, Schneeman BO (1990) Dietary fiber and gender: effect on postprandial lipemia. Am J Clin Nutr 52:837–845
24. Thorsdottir I, Andersson H, Einarsson S (1998) Sugar beet fiber in formula diet reduces postprandial blood glucose, serum insulin and serum hydroxyproline. Eur J Clin Nutr 52:155–156
25. USDA (2008) National Nutrient Database for Standard Reference, release 21. In: United States Department of Agriculture, The Nutrient Data Laboratory
26. Weickert MO, Pfeiffer AF (2008) Metabolic effects of dietary fiber consumption and prevention of diabetes. J Nutr 138:439–442
27. Wells JC (2007) Sexual dimorphism of body composition. Best Pract Res 21:415–430
28. Wheeler ML, Pi-Sunyer FX (2008) Carbohydrate issues: type and amount. J Am Diet Assoc 108:S34–S39
29. WHO (1999) Part 1: diagnosis and classification of diabetes mellitus. In: Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. World Health Organization, Geneva
30. Wolever TM, Campbell JE, Geleva D, Anderson GH (2004) High-fiber cereal reduces postprandial insulin responses in hyperinsulinemic but not normoinsulinemic subjects. Diabetes Care 27:1281–1285