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ORIGINAL CONTRIBUTION

Fibre in beverages can enhance perceived satiety

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Abstract
Background A high intake of dietary fibre has been suggested to support the regulation of energy intake and satiety, which could contribute favourably to the increasing obesity problem.
Aim of the study To investigate the effects of three fibres differing in chemical and physical properties on perceived satiety and hunger-related attributes.
Methods A total of 19 healthy volunteers, age 18–30, mean BMI 23.2 kg/m^2 participated in the study. Measurement of food and satiety-related perceptions with ten attributes was performed by using 10-unit graphic intensity scales during a 120 min period after the ingestion the sample. The attributes evaluated were satiety, hunger (unipolar and bipolar scale), appetite, fullness, desire to eat something/sweet/savoury/the sample food and thirst. The sample foods used were a beverage without fibre, a guar gum beverage, a wheat bran beverage, an oat β-glucan beverage and wheat bread was used as the control. The fibre content of the samples was 0 g (beverage without fibre), 2.4 g (wheat bread), 7.8 g (guar gum) or 10.5 g (wheat bran and oat β-glucan beverage) per 400 g/1,000 kJ portion.
Results The area under curve (AUC) for perceived satiety was higher (169 vs. 83 cm min; t test $P = 0.026$) and the desire to eat was lower (AUC −179 vs. −83 cm min; t test $P = 0.008$) for the guar gum beverage as compared to the beverage without fibre. Also the beverage with oat β-glucan increased fullness and showed a trend of increasing perceived satiety and decreasing the desire to eat more than the beverage without fibre.
Conclusions Our results support the idea that dietary fibre in beverages can enhance their perceived satiety and decrease the desire to eat more than a beverage without fibre.

Keywords Satiety response · Beverages · Dietary fibre · Guar gum · Oats · Wheat · β-Glucan

Introduction

Obesity is becoming an increasingly common health problem worldwide [26]. In addition, obesity is one of the risk factors in metabolic syndrome and type 2 diabetes, requiring a lot of resources from the public health care system [26]. Effective tools for stopping this progress are actively being sought.

The intake of dietary fibre has been linked with the regulation of energy intake and satiety and therefore could contribute favourably to the obesity problem. A meta-analysis of 22 studies concluded that a 14 g increase in fibre intake is linked to a 10% reduction in energy intake and 1.9 kg reduction in weight during 3.8 months [8]. In overweight or obese persons, the reductions were even

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larger. Increased consumption of whole grains [12] or dietary fibre [13] has shown to protect from weight gain. An inverse relationship between dietary fibre intake and body mass index (BMI, calculated as kg/m^2) has been shown in women [9].

Dietary fibre is a nutritional concept and covers a group of substances with different chemical and physical properties. The physiological effects of fibre depend on its chemical and physical properties and thus vary between different types of fibre. There are several mechanisms on how dietary fibre may influence regulation of food intake [2, 8]. Dietary fibre lowers the energy density of food, as it is not absorbed in the intestine. Mastication of food naturally rich in dietary fibre requires more time and effort, which allows more signals mediating satiety sensations to the brain. Dietary fibre adds bulk and weight to the diet and thus replaces energy from other nutrients. The viscosity-forming capacity of water-soluble fibres, such as guar gum and oat β-glucan, has been suggested to be crucial in its effect on satiety-related attributes. Soluble fibres, such as oat β-glucan, increase the viscosity of the chyme in the gut and therefore slow down the gastric emptying time, prolong the small intestine transit time and absorption rate of nutrients, which may increase satiety. The modified absorption rate of nutrients also affects the hormonal responses of the gut, which slows down the gastric emptying time and may enhance ileal brake. In addition, the gel-forming capacity of soluble fibres may also promote gastric distension, which promotes satiation and satiety after meals via satiety-mediating signals to the central nervous system. One possible mechanism is also the decrease in the absorption of energy nutrients (fat, protein) because of the physical barrier between nutrients and intestinal mucosa formed by dietary fibre [2, 8].

The satiating effects of fibre have been tested in many short-term studies, using a variety of fibres, doses and food matrices. Results have varied depending on the type of fibre used. Among soluble, viscous fibres such as guar gum [3, 17], psyllium [4, 5], pectin [23] and β-glucan [10], some of the studies have shown reduced hunger and/or appetite perceptions after consumption of the test food compared to low/no fibre condition [3, 17, 23]. The soluble, non-viscous fibres have shown only very limited effects or no effects on perceived satiety even at very large doses [20]. Among insoluble fibres two studies showed that wheat fibre did not affect satiety [6, 25], but four other studies with wheat bran demonstrated increased satiety and fullness [4, 19, 24] or decreased hunger [5] after ingesting the test food compared to a habitual breakfast [24], low-fibre control food [19] or soluble fibre [4, 5].

The comparison of the effects of different fibres on satiety is difficult due to various doses and food matrices used and the results are somewhat inconsistent. In addition, in most of the studies the carrier foods used have been solid; only in two studies beverages were used [17, 23]. Beverages could be another product alternative for increasing dietary fibre intake. The objective of this study was to investigate how soluble viscose (guar gum), partly soluble viscose (oat fibre) and insoluble (wheat bran) fibre preparations affect perceived satiety using beverages as carrier products.

Materials and methods

Subjects

A total of 19 volunteers participated in the study. They were recruited from the Helsinki University of Technology. The mean age of the volunteers was 23.8 years (range 18–30 years). The mean BMI of the participants was 23.2 kg/m^2 (range 19–28.3 kg/m^2).

Samples

The test products were three beverages with three types of added fibre. The guar gum fibre was soluble, fibre in wheat bran insoluble and oat β-glucan preparation contained both soluble and insoluble fibre.

The beverages were prepared by mixing all the ingredients (Table 1) together at room temperature. The target fibre content of the beverages was 10.5 g/portion. The wheat bran was milled (particle size circa 0.17 mm) before use. The oat β-glucan preparation was mixed with the beverage base just before consumption to avoid excessive viscosity formation and keep it drinkable. The beverage with guar gum became so thick with the targeted fibre content so that 7.8 g of fibre per portion was the maximum possible amount in this particular sample. The internal reference sample used was a beverage without fibre, and the wheat bread was used as an external reference sample for calculating the satiety index [7]. Each beverage portion weighted 400 g and the energy content was 1,000 kJ ($\sim$ 239 kcal, 1 kcal = 4.186 kJ).

Procedure and methods

At the beginning of the study, the subjects completed the Three Factor Eating Questionnaire (TFEQ) [21] concerning their eating behaviour and a food frequency questionnaire for assessing food habits. Scores of these questionnaires were not used as selection criteria. Based on the TFEQ the subjects' mean 'cognitive restraint' score was 5.9 (SEM 0.9), 'uncontrolled eating' score 4.9 (SEM 0.5) and 'hunger' score 4.8 (SEM 0.7). Based on the food frequency

Table 1 The ingredients of the beverage samples (g) and nutrient value

	A beverage without fibre (reference)	Guar gum beverage	Oat β-glucan beverage	Wheat bran beverage	Wheat bread (reference)
Ingredients					
Guar gum[a] (g)	–	10.0	–	–	
Oat β-glucan preparation[b] (g)	–	–	30.0	–	
Wheat bran[c] (g)	–	–	–	21.8	
Black currant juice (g)	40.0	40.0	40.0	40.0	
Strawberry juice (g)	20.0	20.0	20.0	20.0	
Sugar (g)	30.0	30.0	17.9	29.8	
Maltodextrin (g)	8.0	6.8	–	–	
Water (g)	302.0	293.2	292.1	288.4	
Total (one portion, g)	400	400	400	400	
Nutrient value					
Carbohydrates (E %)	100	98	78	92	74
Protein (E %)	0	1	11	5	14
Fat (E %)	0	1	11	3	12
Dietary fibre (g)	0	7.8	10.5	10.5	2.4
Energy content (kJ)	1,000	1,000	1,000	1,000	1,000

[a] Fibre content 78%. Vidocrem AI. Energy content 1,429 kJ (342 kcal)/100 g, protein < 7 g/100 g, sugars < 1 g/100 g, fat < 1.5 g/100 g, dietary fibre 78 g/100 g. Manufactured by Unipektin AG, Germany

[b] Fibre content 34% of which 50% β-glucan. Energy content 1,100 kJ (260 kcal)/100 g, protein 22 g/100 g, carbohydrates 18 g/100 g, fat 11 g/100 g, dietary fibre 34 g/100 g, of which 17 g β-glucan. Natureal GI-trim®, marketed by Valioravinto PLC., Finland

[c] Fibre content 48%. Sydänystävä®. Energy content 650 kJ (150 kcal)/100 g, protein 14 g/100 g, carbohydrates 11 g/100 g, of which sugars 2 g/100 g, fat 5.6 g/100 g, dietary fibre 48 g/100 g. Manufactured by Ravintoraisio PLC., Finland

questionnaire all respondents used white bread and 75% of the respondents used fruit or berry-based beverages at least occasionally.

Before the actual study the subjects were trained in the procedure and the use of rating scales with rye bread. The study sessions (totally 6, 1 training with rye bread, 4 with beverages and 1 with wheat bread) were carried out in the morning after a minimum of 8 h fasting. There was at least 1 day between the sessions.

At the beginning of each session the subjects completed a questionnaire about their fibre intake the previous day. The test is developed by the Finnish Bread Information [22] to give a rough estimation of fibre intake in Finland, but the name of the test in this study was changed from ‘fibre test’ to ‘food test’ in order not to focus participants’ attention in the fibre content of the samples. Before ingesting the sample, the subjects rated their satiety-related perceptions. The time used for intake was registered. Subjects rated their satiety-related perceptions immediately after ingestion and after 20, 40, 60, 90 and 120 min from the beginning of ingestion.

Satiety ratings

The satiety-related perceptions were evaluated using 10-unit graphic intensity scales, both unipolar and bipolar, verbally anchored from their ends. A total of 12 attributes were rated, measuring the feeling of satiety, hunger (both unipolar and bipolar scale), fullness, appetite (‘How much do you think you can eat right now?’), desire to eat something and desire to eat something sweet/savoury/the sample food. The thirstiness, alertness and overall feeling (extremely unwell/extremely well) were measured as control questions. In addition to these attributes, the subjects rated the expected and perceived pleasantness and fillingness of the sample just before and after ingesting the sample (not reported here). The data were collected using computerised data-collecting system (CSA, Computerized Sensory Analysis System, Compusense Inc., Guelph, Canada, Compusense 5, version 4.6).

Viscosity measurement

Measurement of viscosity was performed with StressTech rheometer (CC 25 CCE, Reologica Instruments AB, Sweden) at a shear rate of 50/s at room temperature.

Data analysis

The absolute satiety-related ratings of each subject were standardised with the baseline values of each subject and

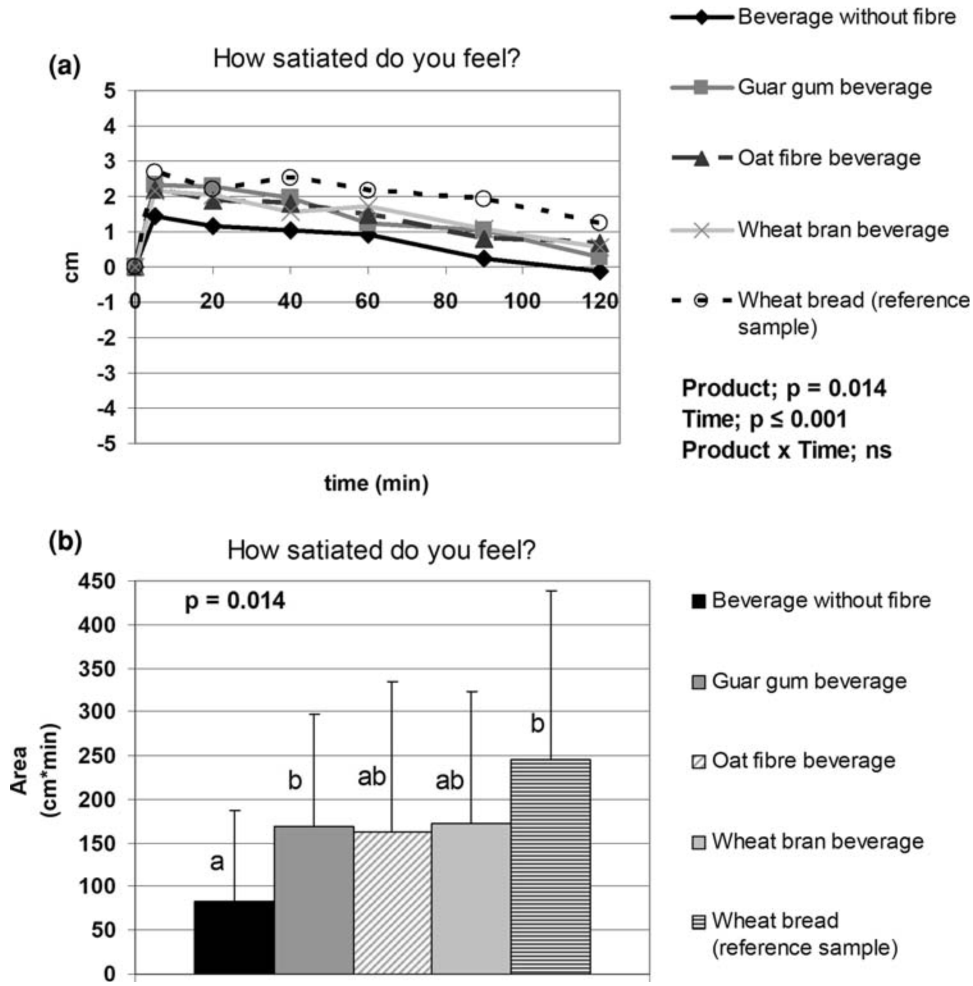


Fig. 1 **a** Changes in the perception of satiety during the 120 min follow-up for each sample. The mean of 19 subjects. **b** The total AUC of satiety (120 min) and standard deviations. *Different letters* above each bar represent statistically significant differences between samples (significance level $P < 0.05$)

study visit by deducting the rating given before taking the sample from the ratings after this. This means that the ratings of each assessor were standardised to start from zero (0). Graphical curves were drawn as a function of time and the area under curve (AUC, cm min) was calculated. The possible area under/over the starting level was subtracted.

The satiety index (SI) represents the short-term satiating effect of a sample food in relation to wheat bread with equal energy content [7]. The SI for the reference wheat bread is always 100. A SI less than 100 indicates that the sample food is less satiating than the control wheat bread, and a SI above 100 indicates that the sample food is more satiating than the control wheat bread with an equal amount of energy. The SI was calculated by dividing the mean AUC of each sample by the mean AUC of the wheat bread sample over all of the assessors. In the later analyses, the mean SI of each sample was used.

The Repeated Measures General Linear Model (GLM repeated) was used in the statistical analysis of the satiety-related results. If differences between the products were found, further analyses were conducted with Paired *T* test.

SPSS software (versions 12.0.1 and 14.0, SPSS Inc. Chicago, IL, USA) was used for the statistical analysis.

Results

Viscosity of the samples

The viscosity of the reference beverage without fibre, wheat bran beverage, oat β-glucan beverage and guar gum beverage was 1.7, 2.6, 33.5 and 1740 mPas, respectively, at the moment of ingestion. The viscosity of the oat β-glucan beverage increased to 200 mPas after 20 min from preparation of the sample.

Satiety-related perceptions

Increasing satiety

The perceived satiety was highest directly after eating the sample and, during the 2-h follow-up time, it decreased back to its initial level or close to it (Fig. 1a). There were differences between the samples in the total AUC of the samples [$F(4, 72) = 3.36$; $P = 0.014$] (Fig. 1b). The guar gum beverage increased the perceived satiety more than the beverage without fibre (83 cm min) (t test value −2.43, $P = 0.026$). Also the wheat bran beverage (t test value 1.82, $P = 0.085$) and the oat β-glucan (t test value 1.63, $P = 0.121$) beverage seemed to have greater AUCs than the reference beverage without fibre, but the differences were not statistically significant. Wheat bread received the highest AUC of satiety, 246 cm min, being significantly higher compared to the reference beverage without fibre (t test value 3.39, $P = 0.003$).

The samples differed statistically significant regarding their ability to increase fullness on a bipolar scale [$F(4, 72) = 3.37$; $P = 0.014$]. The reference beverage increased the perceived fullness the least (AUC 54 cm min) and it differed from the oat β-glucan beverage (169 cm min) (t test value 2.35, $P = 0.03$). The differences between the reference beverage and wheat bran beverage (t test value 1.81, $P = 0.086$) and guar gum beverage (t test value −2.045, $P = 0.056$) were close to the statistical significance, the AUC for wheat bran beverage being 121 cm min and 132 cm min for the guar gum beverage. The fullness evaluated on the unipolar scale did not differentiate the samples.

Decreasing general willingness to eat

The desire to eat something was lowest directly after eating the sample and, during the 2-h follow-up time, it returned back to its initial level or close to it (Fig. 2a). There were almost statistically significant differences between the samples in the total AUC of the samples [$F(4, 72) = 2.46$; $P = 0.053$] (Fig. 2b). The guar gum beverage (AUC 183 cm min) decreased the desire to eat something more than the beverage without fibre (−79 cm min) (t test value 2.99, $P = 0.008$), and also the difference between oat β-glucan beverage (−197 cm min) and the reference beverage without fibre was close to the statistical significance (t test value −1.93, $P = 0.070$). The AUC of the decrease in the desire to eat something for wheat bread was greater than the AUC of the reference beverage without fibre (t test value −3.23, $P = 0.005$). Hunger and appetite did not differentiate the samples.

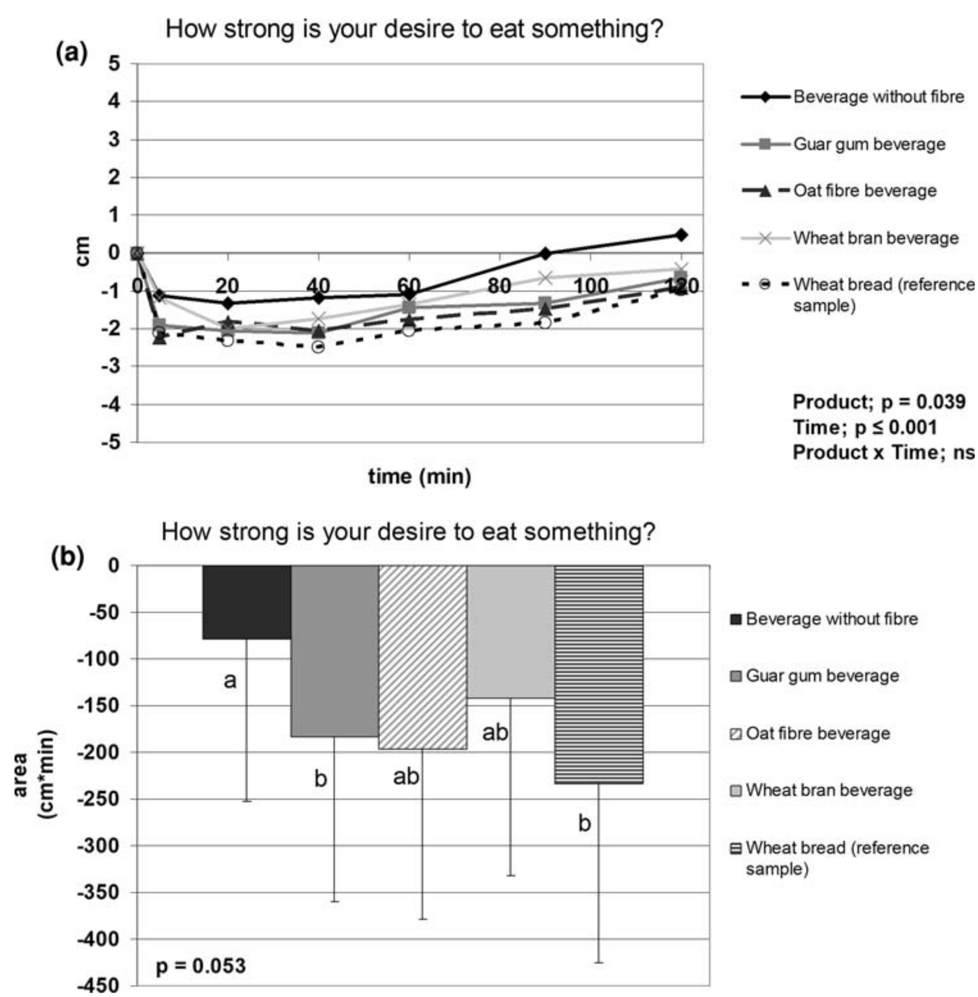
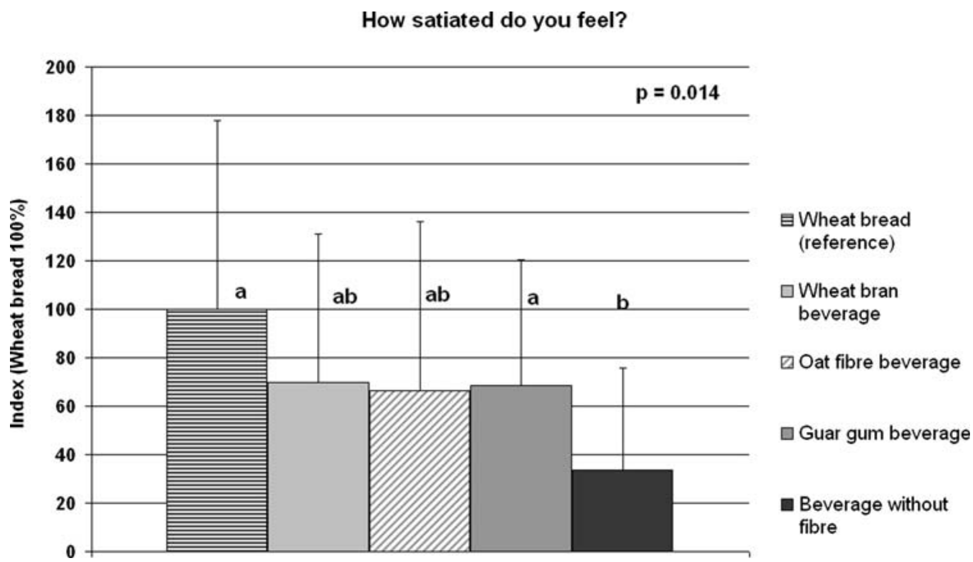


Fig. 2 **a** Changes in the desire to eat something during 120 min follow-up for each sample, standardised with the baseline value. The mean of 19 subjects. **b** The total AUC of the desire to eat something (120 min) and standard deviations. *Different letters* below each bar represent statistically significant differences between samples (significance level $P < 0.05$)

Fig. 3 The satiety index of the samples and standard deviations. *Different letters* above each bar represent statistically significant differences between samples (significance level $P < 0.05$)



Thirst and sensory-specific willingness to eat

The control attribute perceived thirst did not differentiate the samples. The desire to eat the sample food decreased the least with the consumption of the reference beverage without fibre (AUC −141 cm min) and decreased most after the consumption of the beverage with wheat fibre (−397 cm min) [$F(4, 72) = 4.16$; $P = 0.004$]. The 'desire to eat something savoury' attribute followed the results of the 'desire to eat something' attribute, the reference beverage having the smallest AUC (−79 cm min), guar gum and oat β-glucan beverage both having the AUC −125 cm min and wheat bread having the largest AUC −241 cm min. The desire to eat something sweet did not differentiate the samples.

There were no changes in overall feeling or alertness during the 120 min follow-up time.

Satiety index

There were differences in the SI of the samples [$F(4, 72) = 3.35$; $P = 0.014$] (Fig. 3). All the beverages had SI below 100. Compared to the reference beverage without fibre (SI 34), the guar gum beverage (SI 69) (*t* test value −2.42, $P = 0.026$) produced significantly higher satiety. In addition, the SI of the wheat bran beverage (SI 70) and the oat β-glucan (SI 66) beverage were higher than that of reference beverage without fibre, but the differences were not statistically significant due to a greater inter-individual variation.

Discussion

The aim of the study was to investigate the effect of dietary fibres differing in chemical and physical properties on perceived satiety of beverages.

Although not statistically significant in all single measures, the results are constant in showing the effect of fibre in beverages to increase perceived satiety. The guar gum beverage had the strongest effect on the perceived satiety compared to the beverage without fibre. Also the oat β-glucan beverage and wheat bran beverage both showed the same trend compared to the reference beverage without fibre, although the difference was not statistically significant. In an earlier study orange juice containing guar gum (40 g/day) did not affect hunger or satiety ratings but reduced the average energy intake [17]. In another study described in the same paper, a guar gum supplementation (20 g/day) reduced hunger and increased satiety at 4 MJ energy level but not at 6 MJ energy level.

Other studies carried out with guar gum but using a solid carrier food have showed variable results. A nutrition bar containing guar gum (5.7 g guar gum + 9.1 g other fibre) increased the perceived fullness and decreased hunger sensations compared to a reference bar (6.4 g dietary fibre) [3], but a finding to the contrary was made with a breakfast bar with alginate and guar gum (total dietary fibre 4.49 g) versus reference bar (total dietary fibre 0.62 g) [15]. In our study, the effect of guar gum on satiety-related perceptions was detected at an energy level of 1 MJ/sample (∼238 kcal) and in another study at 300 kcal/sample [3]. The breakfast bar containing alginate and guar gum contained 196 kcal of energy [15], with no effect on satiety-related attributes. It could be suggested that to achieve an increasing effect on satiety, in addition to fibre, the carrier food needs to contain a certain amount of energy. On the other hand, a very high energy level may mask the effect of fibre on hunger and satiety, as the energy content of the food has a significant influence on hunger per se [11]. Also, a diet high in energy may mask the satiety-related effects of fibre supplementation in the diet [17].

In our study the most viscous sample, the beverage with guar gum, and the solid food, wheat bread, had the clearest effect on satiety and desire to eat compared to the beverage without fibre. The effect of guar gum on satiety could be mediated through its high viscosity, as the viscosity of food has been suggested to improve satiety [20]. Earlier a significant inverse effect of viscosity on hunger ratings was detected in beverages [16]. Contrary to this, viscosity of rice milk did not have an effect on hunger ratings [18].

Also, the beverage containing oat β-glucan, another soluble fibre in our study besides guar gum, increased fullness and showed a trend of having a higher satiety index and AUC of satiety and decreasing the 'desire to eat something' more than the beverage without fibre, although the results just approached statistical significance. In another study, a smaller (2 g) dose of barley β-glucan did not affect satiety ratings compared to isocaloric glucose load [10]. A trend of soluble fibre (22 g) suppressing hunger ratings more than insoluble fibre (22 g) after 11.5 h from ingesting the sample food was detected [5]. This result suggests that different types of fibre may regulate appetite during a varying time span.

However, in our study, the differences in the viscosity of the samples do not completely explain the observed differences in their ability to suppress the desire to eat and increase satiety. The viscosity of the beverage without fibre and the wheat bran beverage was almost the same, 1.7 and 2.6 mPas, respectively. Still, the satiating power of the wheat bran beverage seemed to be stronger, although not statistically significant. One suggested mechanism through which insoluble fibre could affect satiety is via more intense mastication causing an increased amount of satiety-mediating signals to the brain [2]. However, our test food was a beverage not requiring mastication.

In our study, the beverages (liquid foods) were all less satiating than wheat bread (a solid food). Similarly, peanut butter had a smaller ability to reduce hunger compared to peanuts equal in energy and almost equal in weight [11]. Supporting this finding, the compensatory system for energy intake has also been suggested to be less sensitive to energy ingested from liquid foods than solid foods according to a meta-analysis [14]. Contrary to this, no difference could be found between the equal energy preloads of a beverage and cookies in their ability to decrease hunger ratings, desire to eat or reduce energy intake following the preload [1].

The satiety index of the samples represented well the other satiety and appetite-related results of the samples. Wheat bread had the highest index, and the index for the beverage without fibre was only about half of the indices for fibre-containing beverages. The comparison with our results to other satiety index scores [7] is difficult, as they did not include any beverages in the test.

There are some methodological aspects to be taken into account. The statistical significance of the differences between samples was relatively low, on both sides of $P = 0.05$, although the results are seemingly clear with differences between the means of the samples. However, the distributions around means are high, which indicates that there are big individual differences. The changes in the ratings could be dependent on the starting levels of the assessments. This may increase variation, which makes it difficult to achieve significance levels in the differences between samples. Thus, it would be essential to improve the methods to measure perceived satiety and hunger. This could be achieved by increasing the sample size, having a longer follow-up time and/or increasing the accuracy in the use of scales by taking into account the personal starting levels of each participant by rating the changes in the feelings compared to the starting level right before the test.

Conclusions

Our results support the idea that dietary fibre in beverages can enhance their perceived satiety and decrease the desire to eat more than a beverage without fibre. Thus, fibre-containing beverages could be suitable alternatives when beverages are used to increase satiety between meals, but they are still less satiety producing than solid foods, like white wheat bread. The viscosity generated by soluble fibres probably had a central role in their ability to affect satiety-related perceptions, but did not completely explain the observed differences between the samples. However, the effect of enhanced short-term satiety on actual food intake and weight management should be studied in long-term studies.

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