No effect of added \( \beta \)-glucan or of fructooligosaccharide on appetite or energy intake\(^{1-3} \)

Harry PF Peters, Hanny M Boers, Edward Haddeman, Sergey M Melnikov, and Fernando Qvyjt

ABSTRACT

Background: An increase in gastrointestinal viscosity or colonic fermentation is suggested to improve appetite control and reduce food intake. It has been proposed that \( \beta \)-glucan and fructooligosaccharide (FOS) are food ingredients that increase gastrointestinal viscosity and colonic fermentation, but the results are inconclusive.

Objective: The objective was to test the effect of FOS, \( \beta \)-glucan, or a combination thereof on appetite ratings and food intake over 2 consecutive days.

Design: In a 4-way balanced-order, crossover, double-blind design, 21 healthy volunteers (mean body mass index (in kg/m\(^2\)) 25.9) consumed a meal-replacement bar at 0900 and an ad libitum lunch at 1300 on 2 consecutive days. On day 1 only, the subjects consumed a second (identical) bar at 1700 and a fixed snack at 1900. The control bar contained 0.3 g \( \beta \)-glucan from 6.8 g oats (control), and the 3 equicaloric test bars contained an additional 0.9 g \( \beta \)-glucan (from 8.0 g barley), 8 g FOS, or 0.9 g \( \beta \)-glucan + 8 g FOS. Appetite scores and subsequent ad libitum test meal intakes were measured. Viscosities in response to bar consumption were determined under simulated gastric conditions. The results were analyzed by analysis of covariance.

Results: The addition of \( \beta \)-glucan, FOS, or a combination thereof did not affect appetite ratings or food intake, although the addition of \( \beta \)-glucan to the bar doubled gastric viscosity (841 compared with 351 mPa - s).

Conclusions: Consumption of \( \beta \)-glucan, FOS, or a combination thereof in meal-replacement bars at the levels tested for 2 consecutive days does not improve appetite control. Efficacy may have improved if the consumption period was longer, if the content of \( \beta \)-glucan was greater, or if a form of \( \beta \)-glucan that generates even higher gastric viscosity was consumed. This trial was registered at clinicaltrials.gov as NCT00776256. Am J Clin Nutr 2009;89:58–63.

INTRODUCTION

Meal-replacement products are effective at reducing body weight in persons following an overall diet plan (1). However, perceived hunger has been shown to be a significant predictor of failure to lose weight in clinical trials (2). Delaying the return of hunger after consumption can potentially increase consumer satisfaction with meal-replacement bars and other food products and encourage long-term compliance with a reduced-energy diet.

Satiety feelings on a meal-to-meal basis are largely determined by gastrointestinal (GI) stimuli (3, 4). One proposed route toward enhancing satiety is the use of selected fibers to prolong gastric emptying and/or small intestinal transit time (5) or to increase short-chain fatty acid (SCFA) production in the colon (6, 7).

One of the fibers proposed to enhance satiety is \( \beta \)-glucan, which increases the viscosity of GI tract contents (8). Oats and barley contain \( \beta \)-glucan, but the amount and type of \( \beta \)-glucan and the food in which the fiber is given differs between various sources. This might explain why the current literature is inconsistent. Both positive (9–13) and negative (14–16) effects on satiety and energy intake have been reported. However, the amount of \( \beta \)-glucan in whole oats is quite low. We therefore compared a barley relatively higher in \( \beta \)-glucan with oats.

If the satiety effects are attributable to viscosity, it is critical to show that the addition of \( \beta \)-glucan meaningfully increases the viscosity of the ingesta. In addition to the effects on viscosity, some fermentable fibers have been shown to increase satiety or satiety hormones (17–19). This may be attributed to the production of SCFAs during their colonic fermentation, which stimulates colonic L cells to produce several satiety hormones [e.g., peptide YY (PYY) and glucagon-like peptide-1 (GLP-1)] (6).

In a recent study it was shown that the consumption of meal-replacement bars containing 8 g fructooligosaccharides (FOS, also known as oligofructose) twice per day increased satiety and reduced food intake (20). The same amount was tested in the current trial.

It takes several hours for these fermentable carbohydrates (that are undigestible in the small intestine) to reach the colon and thereafter several more hours (up to 24 h) to be fully digested by the colonic microflora (with consequent production of SCFAs). Therefore, the effects of FOS might be apparent not on the day of consumption itself but on the next day. Consequently, the effects of the combined consumption of barley and FOS might be observed both on the day of consumption (viscosity) and on the next day (SCFAs). Because barley also contains some fermentable fibers, the effects of these fibers might also occur the day after consumption. The aim of the study, therefore, was to quantify the effect of meal-replacement bars containing FOS, \( \beta \)-glucan, or both on satiety and food intake over 2 consecutive days.

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\(^1\) From Unilever Food and Health Research Institute, Unilever Research & Development, Vlaardingen, Netherlands (HPFP, HMB, EH, and SMM), and Unilever Research & Development, Covington, TN (FQ).

\(^2\) Research support was provided by Unilever.

\(^3\) Reprints not available. Address correspondence to HPFP Peters, Unilever Food and Health Research Institute, Olivier van Noortlaan 120, PO Box 114, 3130 AC Vlaardingen, Netherlands. E-mail: harry.peters@unilever.com.

Received July 16, 2008. Accepted for publication October 29, 2008.

SUBJECTS AND METHODS

Subjects

The volunteers were recruited from local area of the research center. Initial recruitment started in February 2007. Selection criteria were as follows: age 18–60 y, body mass index (BMI; in kg/m²) ≥21 and ≤32.0, apparent health (measured by questionnaire), and no use of medicines judged likely to influence the study results. Only normal and low-restraint eaters were included (21); men with a BMI < 27 (restraint score ≤ 2.37), men with a BMI ≥ 27 (restraint score ≤ 3.04), women with a BMI < 26 (restraint score ≤ 3.24), and women with a BMI ≥ 26 (restraint score ≤ 3.41). Any subject with a tendency toward a diagnosable eating disorder (anorexia nervosa or bulimia) was also excluded. This was tested by using the Dutch translation of the SCOFF questionnaire, which contains 5 yes/no questions related to eating disorder symptoms. Persons with ≥2 “yes” responses were excluded from participation (22).

Study design

The study protocol was approved by the Wageningen Dutch Ethical Committee in the Netherlands. The study used a balanced treatment order, random allocation, 4-way crossover design. For 4 wk, each volunteer visited the test facility on the same 2 consecutive weekdays. On both of these days, the subjects consumed a meal-replacement bar (either a control bar or one of the 3 test bars described below) for breakfast at 0800. The bars are specifically designed and promoted to substitute for any main meal. They are controlled in energy content, but fortified with significant quantities of essential vitamins and minerals. These commercially available bars are commonly consumed as a breakfast meal.

At 1200, the subjects received an ad libitum lunch. On the first treatment day only, the subjects consumed another meal-replacement bar (either a control bar or one of the 3 test bars described below) for breakfast at 0800. The bars are specifically designed and promoted to substitute for any main meal. They are controlled in energy content, but fortified with significant quantities of essential vitamins and minerals. These commercially available bars are commonly consumed as a breakfast meal.

Test foods

Four products were evaluated, the compositions of which are shown in Table 1: 1) control bar: regular meal-replacement bar (high-protein granola bar, chocolate chip; Slim-Fast, Unilever, Covington, TN; 56.0 g, 194 kcal) containing, among other ingredients, 6.8 g oats, 3.9 g corn syrup, and 1.2 g FOS (Raffilose P95; Beneo-Orafti, Tienen, Belgium); 2) barley bar (treatment 1): same as the control bar but with extra barley and no oats (57.0 g, 195 kcal, 3.9 g corn syrup, 1.2 g FOS, and 8.0 g barley); 3) FOS bar (treatment 2): same as the control bar but with less oats and extra FOS (58.5 g, 189 kcal, 2.6 g oats, 3.9 g corn syrup, and 8.0 g FOS); and 4) FOS + barley bar (treatment 3): same as the control bar but with extra FOS and barley and no oats or corn syrup (60.0 g, 197 kcal, 8.0 g FOS, and 8.0 g barley).

The concentration of β-glucan in whole oats is quite low. The typical content of β-glucan in whole oats is ≈3% and in oat bran is ≈6.5%. In the current study we compared a barley (Sustagrain whole grain barley; ConAgra Mills; 31 g/100 g fiber, of which 14 g/100 g is β-glucan) relatively higher in β-glucan than in oats, whereby 6.8 g rolled oats in the control bar was replaced by 8.0 g barley. This resulted in an increase of 1.6 g total fiber, of which the main component was β-glucan (0.3 g in the control bar and 1.2 g in the barley bar). The amount of barley was judged to be the maximum amount of barley that could feasibly be added to the bar while still maintaining acceptable palatability. The level of FOS used was previously shown to generate significant physiologic effects indicative of colonic fermentation and satiety hormone production (18, 23–27).

Rheology of bars under simulated gastric conditions

The bars were first minced in a standard kitchen blender to mimic oral mastication. To mimic gastric digestion, artificial gastric juice was added progressively at a flow rate of 1.5 mL/min for 30 min into a digestion unit through a peristaltic pump. The digestion unit was prepared by adding 1 g lipase (52.04 U/mg from Rhizopus orizae; Fluka, Germany) and pepsin (708.0 U/mg from hog stomach; Fluka, Germany) in 100 mL deionized water and then mixing with 12 mL of 37% HCl. Deionized water was added to adjust the total volume to 250 mL. The concentration of HCl added was varied to obtain a gradual decrease in pH to 2.0.

The digestion unit consisted of a jacketed glass cell of 300 mL held at 37°C by a through-flow water bath. A thin Hamilton Biotrode pH electrode (Hamilton Bonaduz AG, Switzerland) was used to measure pH. ATA-AR 1000 rheometer was used to measure viscosity at 108 rpm. To mimic gradual dilution, 40 g of the bars was gradually mixed with 160 mL of the liquid in the simulated stomach.

Subjective feelings of hunger, satiety, and palatability

Volunteers arrived at the test facility at 0745 h in the morning and received the test products at 0800. They were required to

TABLE 1

<table>
<thead>
<tr>
<th>Test bar</th>
<th>Weight</th>
<th>Energy</th>
<th>Fat</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Fiber</th>
<th>Sugar</th>
<th>Oats</th>
<th>Barley</th>
<th>β-Glucan</th>
<th>FOS</th>
<th>Corn syrup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>56.0</td>
<td>193</td>
<td>5.7</td>
<td>18.7</td>
<td>18.9</td>
<td>2.5</td>
<td>10.6</td>
<td>6.8</td>
<td>0</td>
<td>0.3</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Barley</td>
<td>57.0</td>
<td>195</td>
<td>5.8</td>
<td>19.1</td>
<td>19.0</td>
<td>4.1</td>
<td>10.6</td>
<td>0</td>
<td>8.0</td>
<td>1.2</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>FOS</td>
<td>58.5</td>
<td>189</td>
<td>5.4</td>
<td>18.1</td>
<td>22.3</td>
<td>8.1</td>
<td>11.0</td>
<td>2.6</td>
<td>0</td>
<td>0.3</td>
<td>8.0</td>
<td>3.9</td>
</tr>
<tr>
<td>FOS + barley</td>
<td>60.0</td>
<td>199</td>
<td>5.8</td>
<td>19.1</td>
<td>22.5</td>
<td>10.2</td>
<td>10.0</td>
<td>0</td>
<td>8.0</td>
<td>1.2</td>
<td>8.0</td>
<td>0</td>
</tr>
</tbody>
</table>

1 The fiber type was supplied by replacing oats with barley, fructooligosaccharides (FOS), or a combination thereof.
2 From oats or barley.
consume the test food within 15 min. The subjects’ self-assessments of feelings of hunger/satiety and fatigue were measured by means of a mark on a 60-mm line EVAS (28) every 0.5 h from 0800 to 2000 h on the first treatment day and from 0800 to 1700 on the second treatment day. The scale items were “appetite for a meal,” “appetite for a snack,” “hunger,” “how much do you want to eat,” “satiety,” and “fullness.” These items were anchored at the low end with the most negative or lowest intensity feelings (ie, “extremely unpleasant” and “not at all”) and with opposing terms at the high end (ie, “extremely pleasant,” “very high,” and “extreme”), as described by Flint et al (29).

Immediately after consumption of the test food and ad libitum test meals, the overall liking, specifically the palatability of the foods with respect to mouth-feel, taste, and flavor, was also recorded by the volunteers using an EVAS.

**Ad libitum meal intake**

An ad libitum meal consisting of a single dish in unlimited quantities was served at 1200 on both test days. Lunch consisted of a meat and potato casserole on the first day [mashed potatoes, endive, and meat providing (per 100 g) 277 kJ, 3 g protein, 2 g fat, and 10 g carbohydrates] and of macaroni and turkey on the second day [macaroni, turkey, and tomato sauce providing (per 100 g) 430 kJ, 5 g protein, 2 g fat, and 16 g carbohydrates]. Energy intake during both meals was calculated as the difference in the amount of food offered and that remaining. During meals, the subjects sat separately, and each subject received his or her own tray of (preweighed) foods (large amounts).

**Gastrointestinal disturbances**

GI disturbances (nausea, heartburn, belching, abdominal bloating, pain, flatulence, and urge to defecate) and general bodily symptoms (headache, dizziness, and fatigue) were scored electronically on 4-point scales (0 = not, 1 = little, 2 = moderate, and 3 = much). The questions were phrased to refer to symptoms that the subjects might possibly have experienced during the preceding hour.

**Background diet, physical activities, and other measurements**

The subjects were asked to avoid alcohol intake and sports activities on the evening before the first test day. They could choose from a selection of frozen meals, and this same meal was then consumed every test week between 1700 and 1900 on the evening before the first test day. The meals contained no FOS [eg, no bananas, onions, or legumes based on Campbell et al (30)]. Eating after 2200 on the evening before the test day was not allowed; only noncaloric drinks were permitted. This was done to minimize variation in glycyogen stores on the test days (29). The subjects were allowed to leave the test facility from 0815 to 1145 and after finishing their lunch. They were asked to not alter their lifestyle behavior (including mode of transportation) during the study, so that energy expenditure would also be roughly the same during the study days. Sleeping time, mode of transportation, menstrual cycle details, and incidental lifestyle changes were also recorded. Body weight was assessed during each visit before the test meal was given.

During both test days in each week, the subjects were allowed to drink water and noncaloric soft drinks but no food at home. The amounts of the drinks each individual consumed on the first test day were recorded and repeated on the other test days. The subjects were asked to arrive in a fasting state at the Unilever Test Center at 0745. During each test day, only coffee, tea, water, and noncaloric soft drinks (maximum: 150 mL) were allowed each hour, but only immediately after completing the satiety questionnaires. The amounts on the first day were recorded and repeated on the other test days. Sugar and milk were not allowed, but a noncaloric sweetener was permitted.

After receiving their test bars at 0800, the subjects were not allowed to eat, except at 1200 (for lunch) and then between 1900 and 2100. During this 2-h period, the subjects were allowed to consume either 1 or 2 sponge cakes [73 g per cake providing (per 100 g) 1265 kJ, 4 g fat, 7 g protein, 59 g carbohydrates, and 0.6 g fiber]. The amount eaten was recorded and repeated each week.

**Statistical analyses**

The data were analyzed by analysis of covariance with baseline measurement as the covariate. This model takes into account the possible influence of baseline, by correlating the score at baseline with the score at each subsequent time point. The sources of variation taken into account were subject (as a random factor), treatment, period, and the period × treatment interaction. The difference between each treatment and the control was estimated according to Dunnett’s difference test (2-sided). The analysis was done per time point and also for area under the curve by using SAS (version 9.3, PROC MIXED; SAS Institute, Cary, NC).

Feelings of hunger/satiety and likings were measured by means of a mark on 60-mm line EVAS, and scores were converted to 100 mm for analysis. In earlier studies from our research center, a within-subject variance of $\approx$85 mm · min for the area under the curve was found. On the basis of this variance, a confidence limit of 0.05, and a power of 0.8, 18 subjects were required for this experiment. To prevent the presence of a period × treatment effect and to correct for period effects, the experimental design was completely balanced and the subjects were randomly allocated according to a Williams design, which balances the treatments and treatment orders over the periods and subjects. All analyses were done for both study days (day 1 and day 2).

**RESULTS**

As expected, the addition of $\beta$-glucan to the bar greatly increased in vitro gastric viscosity. Viscosity was 841 and 351 mPa · s with the $\beta$-glucan and control samples, respectively, and gradually decreased because of dilution (data not shown). Three subjects dropped out of the study for reasons unrelated to the test products; therefore, only 21 subjects (16 women and 5 men) completed the study. Their mean age was 52.8 y (range: 36–60 y) and their mean BMI was 25.9 (range: 21.7–30.3).

Palatability scores for the bars on days 1 and 2 did not differ between treatments and were relatively high (mean scores: 72 to 76 out of a possible score of 100). The addition of 0.9 g $\beta$-glucan (by replacing oats by barley), 8 g FOS (by partly removing oats), or a combination of FOS and barley did not affect any of the 6 scales for satiety/appetite based on analyses of either single time points or areas under the curve. A representative example for the scoring of hunger is shown in Figure 1.
The addition of β-glucan (barley), FOS, or a combination of FOS and β-glucan also did not significantly affect food intake on day 1 or day 2. On the day 1, food intake was 629, 655, 624, and 651 g (SE: 49) with the control, FOS, barley, and FOS + barley bars, respectively. On day 2, food intake was 595, 612, 608, and 590 g (SE: 44) with the control, FOS, barley, and FOS + barley bars, respectively. Although GI symptoms were occasionally reported, most were rated “little” and some were rated “moderate” (data not shown). These symptoms were not significantly different between the treatment and control groups.

DISCUSSION

Under the current study conditions, β-glucan from barley, FOS, or a combination thereof in meal-replacement bars did not affect appetite or ad libitum food intake when eaten for 2 consecutive days (2 bars on the first day and 1 bar on the second day).

Although β-glucan and FOS were added at relatively high but realistic levels (in terms of both typical dietary exposures and product feasibility), it could be argued that efficacy requires still higher amounts or perhaps longer periods of consumption. The latter could be a particularly relevant issue for FOS, whereas the former could be a particularly relevant issue for β-glucan. The amount of barley used to increase the β-glucan content was judged to be the maximum amount of barley that could feasibly be added to the meal-replacement bar while still retaining acceptable palatability. We wanted to prevent a detrimental effect on palatability because it can affect satiation and/or satiety (31).

In a recent human study, it was shown that consumption of bars containing 8 g FOS twice per day for 2 weeks significantly increased satiety after breakfast and dinner and reduced hunger and prospective food consumption after dinner at the end of those weeks (20). Cani et al hypothesized that FOS could induce satiety because of the release of satiety hormones, particularly GLP-1, stimulated by the production of SCFA in the colon (6, 7). However, Parnell and Reimer (32) found no effects on subjective hunger, PYY, or GLP-1 in subjects who consumed 21 g FOS/d for 12 wk, even though these subjects lost significantly more body weight and had lower ghrelin concentrations than did those who consumed a maltodextrin control (32). In rats, FOS supplementation decreased food intake, apparently via SCFA production or the promotion of intestinal synthesis and portal release of GLP-1 (33–35). Numerous studies have shown that the level of FOS used in the current study should have increased...
fermentation (as would be evidenced by increases in fecal mass, bacterial growth, or production of SCFAs or hydrogen) in both rodents and humans (18, 23–27).

To build on theory derived from previous research, our intention was to assess the magnitude of effects within the context of relatively realistic living conditions and typical diets. Therefore, subjects were free-living, and the measurement of blood variables and of in vivo GI viscosity were not possible. Furthermore, these measurements could have affected the self-reported satiety ratings, which were the key interest of this research.

The question may also be asked whether the quantity of β-glucan in the bar was sufficient to induce a satiety effect. Several studies have shown positive (9–13) as well as negative results (14–16) on satiety and energy intake with oat or barley dietary fiber as sources of β-glucans. However, the amount and type of β-glucan and the food in which the fiber was given differs between the various studies, and may explain why this literature is inconclusive.

A recent trial by Kim et al (15) found that 2 g β-glucan (barley served as cooked cereal with low-fat yogurt) had no acute satiety effect. They concluded that more β-glucan is needed to achieve satiety and weight control. However, if (as is consistently posited) the effect of β-glucan on satiety is mediated by the viscosity in the GI tract, one could argue that it is not fundamentally the amount of β-glucan that is important but its physical effects on the ingesta. At a given amount, this is largely determined by the molecular size and solubility of the β-glucan used (7, 36, 37), which are both very hard to determine. The molecular weight of β-glucans has been reported in the literature to vary from 31 to 3100 (38), which can also change during isolation, purification, and extraction procedures (39, 40). Furthermore, whereas the starting material for the products is mostly not well characterized, the molecular weight of the β-glucan can also become lower during processing (41, 42).

To circumvent the problem of determining the molecular size of the dietary fiber and the influence of processing on it, the rheological behavior of the test bars was tested directly under simulated gastric conditions. Because the measurement of actual GI viscosity is difficult and expensive (it requires magnetic resonance imaging), and the results can be difficult to standardize and replicate, GI viscosity was estimated by in vitro methods. Although generalized in vivo conditions are only approximated by the in vitro procedures, the latter can be standardized and thus reliably replicated (43, 44).

The barley used in the present study was waxy, had no hull, and was rich in dietary fibers (30%), especially in β-glucan (15%). The high content of soluble fibers (β-glucan) in the bar was expected to produce increased gastric viscosity and thus to enhance satiety. Indeed, the in vitro test clearly showed that the barley bars doubled gastric viscosity as compared with the oat bar control, especially during the first 10 min of the experiment. The highest values reached by the barley and oat bars were 0.84 and 0.35 Pa · s, respectively, at a shear rate of 107 rpm. Nevertheless, this level of gastric viscosity might still be too low to generate increases in perceived satiety by itself. Magnetic resonance imaging data from Marciani et al (43) suggest that an 80-fold higher viscosity may be needed for a significant effect on satiety or fullness. (They obtained values of 0.002 and 1.1 Pa · s at 0.5 s⁻¹ for the control and viscous drink, respectively.)

In addition to viscosity and molecular weight, the extractability (or solubility) of β-glucans might influence the physiologic effects of soluble fibers. For example, Mäkeläinen et al (45) showed that increasing the amount of β-glucan in a drink caused an incremental effect on the glucose and insulin responses, with the magnitude of effect much better explained by the amount of extractable β-glucan than by the total amount of β-glucan (45). Similarly to molecular weight, the extractability of β-glucan is also affected by the processing conditions (41, 42).

In conclusion, β-glucan, FOS, or a combination thereof in meal-replacement bars at diet-relevant and product-feasible levels do not diminish hunger when consumed over 2 consecutive days. The bar containing extra β-glucan generated a doubling of in vitro gastric viscosity, and the 2 d duration of consumption should have been sufficient for the FOS to undergo significant colonic fermentation. More intensive conditions (duration of exposure, level, and viscosity of β-glucan) may be required to consistently demonstrate the putative satiety effects of these fibers and are worth testing. However, this needs to be balanced against feasibility issues (especially product quality and GI complaints) to ensure that the results are relevant and practicable.

We acknowledge Anna Ström and David Mela for their comments and editing of the manuscript and Minh-Thien Ngo for the in vitro rheology work.

The authors’ responsibilities were as follows—HPFP: designed the study, interpreted the data, and drafted the manuscript; EH: collected, analyzed, and interpreted the data and participated in drafting the manuscript; HMB and FQ: participated in designing the study and revising the manuscript for intellectual content and approved the final manuscript; and SM: collected and interpreted the data, participated in revising the manuscript for intellectual content, and approved the final manuscript. None of the authors had a conflict of interest. (All authors are employed by a commercial manufacturer of meal-replacement bars.)

REFERENCES


