

## Original Research

# Instant Oatmeal Increases Satiety and Reduces Energy Intake Compared to a Ready-to-Eat Oat-Based Breakfast Cereal: A Randomized Crossover Trial

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**Key words:** oats,  $\beta$ -glucan, satiety, energy intake, physicochemical properties

**Background:** Foods that enhance satiety can help consumers to resist environmental cues to eat and help adherence to calorie restriction. The objective of this study was to compare the effect of 2 oat-based breakfast cereals on appetite, satiety, and food intake.

**Methods:** Forty-eight healthy individuals, 18 years of age or older, were enrolled in a randomized, crossover trial. Subjects consumed isocaloric servings of either oatmeal or an oat-based ready-to-eat breakfast cereal (RTEC) in random order at least a week apart. Visual analogue scales measuring appetite and satiety were completed before breakfast and throughout the morning. Lunch was served 4 hours after breakfast. The physicochemical properties of oat soluble fiber ( $\beta$ -glucan) were determined. Appetite and satiety responses were analyzed by area under the curve. Food intake and  $\beta$ -glucan properties were analyzed using *t* tests.

**Results:** Oatmeal increased fullness ( $p = 0.001$ ) and reduced hunger ( $p = 0.005$ ), desire to eat ( $p = 0.001$ ), and prospective intake ( $p = 0.006$ ) more than the RTEC. Energy intake at lunch was lower after eating oatmeal compared to the RTEC ( $p = 0.012$ ). Oatmeal had higher viscosity ( $p = 0.03$ ),  $\beta$ -glucan content, molecular weight ( $p < 0.001$ ), and radius of gyration ( $p < 0.001$ ) than the RTEC.

**Conclusions:** Oatmeal suppresses appetite, increases satiety, and reduces energy intake compared to the RTEC. The physicochemical properties of  $\beta$ -glucan and sufficient hydration of oats are important factors affecting satiety and subsequent energy intake.

## INTRODUCTION

Overweight and obese individuals are at an increased risk for cardiovascular diseases, diabetes, musculoskeletal diseases, and certain cancers [1]. Worldwide, 3.4 million deaths per year are attributed to being overweight or obese [1]. Research spanning several years suggests that certain components of food can produce significant effects on the regulation of appetite in

the short term. A diet containing these foods could translate into reductions in body weight when coupled with other lifestyle changes [2].

$\beta$ -Glucan is a dietary fiber found in significant amounts in oats and barley [3]. Oat  $\beta$ -glucans are linear polysaccharides that can be viewed as a cellulose chain. Approximately 70% are 4-O-linked units interrupted by 3-O-linked  $\beta$ -D glucopyranosyl units. The (1 $\rightarrow$ 3) linkages occur singly, whereas the

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Abbreviations: RTEC = ready-to-eat breakfast cereal, BMI = body mass index, PBRc = Pennington Biomedical Research Center, VAS = visual analogue scale, AACCC = American Association of Cereal Chemists

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4-O-linked mostly occur in groups of 2 or 3 [4]. Approximately 75% to 78% of the  $\beta$ -glucan content of oats is found in the endosperm cell walls.  $\beta$ -Glucan is generally water soluble and in solution is viscous even at low concentrations [3].

Increased viscosity of gastrointestinal contents delays gastric emptying, prolongs the time during which nutrients are in contact with the small intestine, increases the intestinal area in contact with the nutrients, decreases postprandial glycemia, and promotes the release of gastrointestinal hormones that promote satiety, such as peptide YY and glucagon-like peptide 1 [5–10]. The manner in which a soluble fiber will modify viscosity depends on the amount, solubility under physiological conditions, and molecular weight and structure of the fiber [11].

The effects of  $\beta$ -glucan on appetite and satiety have been assessed in several studies. Whereas some studies demonstrated a beneficial effect on satiety [9,12–16], others showed no effect [17,18]. Thus, it appears that differences in the properties of  $\beta$ -glucan in each food may influence the physiological response. However, most studies do not provide data on the physicochemical properties of  $\beta$ -glucan used in the studies.

In the present study, the effect of an instant oatmeal breakfast on satiety and food intake was compared with that of an oat-based ready-to-eat breakfast cereal (RTEC). Replacing foods in the diet with foods that enhance satiety may be a means of reducing energy intake; hence, the comparator used was the most widely consumed (based on Information Resources Inc. liquid data, 52 weeks ending March 11, 2012) oat-based RTEC in the United States, even though the products differed in their nutrient composition. The viscosity of the 2 breakfast meals,  $\beta$ -glucan content, molecular weight, and radius of gyration were determined. In a previous study using a 250 kcal serving of old-fashioned oats [19], which is processed differently and has a thicker flake than instant oatmeal, it was shown that subjective measures of satiety increased after eating oatmeal compared to the RTEC. A single serving of instant oatmeal (150 kcal) also increased satiety compared to the RTEC [20]. In the present study, it was hypothesized that compared to the RTEC, consumption of a 250 kcal instant oatmeal breakfast meal would result in greater subjective satiety over 4 hours as well as greater reduction in food intake at the end of 4 hours.

## **SUBJECTS AND METHODS**

### **Subjects**

Forty-eight subjects, 18 years of age or older, were enrolled in a randomized, crossover trial. All subjects participated in an initial screening that involved measurement of body weight, height, waist circumference, vital signs (blood pressure, pulse rate), chemistry-15 panel (glucose, creatinine, potassium, uric

acid, albumin, calcium, magnesium, creatine phosphokinase, alanine aminotransferase, alkaline phosphatase, iron, cholesterol [total, high-density lipoprotein, low-density lipoprotein], and triglycerides), complete blood count with differential, and  $\beta$ -HCG pregnancy test–urine (in females of child-bearing potential). To enhance applicability of the hypothesized results, body mass index (BMI) was not a criterion for exclusion but participants were required to be otherwise healthy. Health was further assessed through the administration of a medical screening questionnaire. Female subjects also completed a menstrual cycle questionnaire so that test days would fall within the luteal phase of the menstrual cycle [21]. Exclusion criteria were (1) intake of regular medications other than birth control or hormone replacement therapy; (2) women who were pregnant or nursing; (3) self-reported weight gain or loss of  $\geq 4$  kg in the last 3 months; (4) fasting glucose  $> 126$  mg/dL; (5) dietary restraint score  $\geq 14$ , assessed by the Dietary Restraint Scale of the Eating Inventory [22]; and (6) allergy or intolerance to oats or milk.

The study was approved by the Institutional Review Board of the Pennington Biomedical Research Center, Baton Rouge, where the study was conducted, and all procedures were in accordance with its ethical standards. Study records are available at Pennington Biomedical Research Center. Participants provided written informed consent. The trial was registered on ClinicaTrials.gov with registration number NCT01666574.

### **Study Design**

Each participant was tested on 2 days. On one occasion the breakfast meal consisted of Quaker Instant Oatmeal Flakes (PepsiCo Inc., Barrington, IL) and on the other occasion the breakfast meal consisted of the RTEC, Honey Nut Cheerios, served in random, balanced order. The randomization was done using a random number table, in blocks of 2, by the study statistician, and all study staff except the study dietitian who assigned participants to the groups were blinded until the data were analyzed. The breakfasts contained 363 kcal, consisting of 250 kcal of cereal and 113 kcal of lactose-free, fat-free milk. Oatmeal (66.8 g dry weight) was prepared by adding 1.5 cups boiling water (360 g), stirred, allowed to stand for a minute, and served with 307 g of cold milk to drink. The RTEC (63.6 g dry weight) was prepared by adding 307 g of cold milk and served with 360 g of water to drink. The participants had the option of adding 1 g of Splenda and one-half teaspoon of cinnamon to the oatmeal. If the participant added the Splenda and cinnamon to the oatmeal, they were required to add both, in the same amounts to the RTEC.

At the first test breakfast visit, participants arrived at the center after a 10-hour overnight fast (except water). Participants were also required to refrain from alcohol and strenuous exercise for 24 hours prior to the test meal. Before serving the test meal, electronic visual analog scales (VAS) [23,24] were

administered. Visual analog scales were scored by the computer on a 0 to 100 unit scale and the score was sent directly to the database. Hunger, fullness, desire to eat, and prospective intake were assessed. The subjects were presented with their first breakfast test and given 20 minutes to eat it. Test meals were supervised to ensure that the entire breakfast was eaten. Visual analog scales were then administered at 30, 60, 120, 180, and 240 minutes following the start of the breakfast meal. Four hours after the start of the breakfast meal, subjects were presented with a lunch meal. Participants made a selection at the screening visit from among turkey, ham, roast beef, or vegetable patty sandwiches as well as a calorie-free or calorie-containing beverage. The same preselected sandwich and beverage were presented to the participants along with potato crisps and cookies on both test days, in quantities greater than they could reasonably consume. Each sandwich, crisps, and cookie presentation ranged in energy content from 2600 to 2800 kcal.

The meals were preweighed and participants were presented with a meal that was in excess of what they could possibly eat. They were told to eat to satisfaction over 20 minutes, after which the remains of the meal were weighed. The food intake at lunch was determined by subtracting the weight of the uneaten food from its original weight. The energy and macronutrient intakes were calculated using the U.S. Department of Agriculture's Food and Nutrition Database for Dietary Studies 4.1 and product information [25]. Subjects were asked an open-ended question (How do you feel?) at each of the time points at which the VAS were completed and after the lunch meal to elicit any adverse events. Subjects returned on another day separated by at least a week to repeat the breakfast and lunch tests.

### ***In vitro* Studies**

The conduct of the *in vitro* studies was previously described [20]. Oatmeal was prepared as described in the study design and allowed to rest for one minute. This oatmeal and dry RTEC were first analyzed for their sugar content by high-performance liquid chromatography and total starch content by standard American Association of Cereal Chemists (AACC) procedures [26]. To determine the  $\beta$ -glucan content and physicochemical characteristics, the RTEC and oatmeal were ground to flour. The  $\beta$ -glucan component was extracted from dry ground oat flakes and the RTEC, according to the procedure described by Rimsten et al. [27], and the content was measured using standardized AACC procedures [28]. After extraction, dialysis purification, and drying, the  $\beta$ -glucan was subjected to molecular weight and radius of gyration analysis. For the viscosity measurement, a serving of each breakfast meal was prepared as described in the study design, allowed to rest for one minute, and the viscosity was measured in a process simulating the gastric phase of digestion *in vivo*.

### **Statistical Analysis**

A mixed model analysis of variance for a crossover trial was performed to analyze the following primary outcomes: total energy intake (kcal), weight of food consumed, and intake from fat, protein, and carbohydrate (g). The area under the curve (AUC) for VAS ratings of hunger, fullness, desire to eat, and prospective food intake was determined. The model included factors with fixed effects (sequence effects or residual treatment effects that carry over from test day 1 to test day 2 [hypothesized to be the same when either oatmeal or the RTEC is consumed on test day 1]), test day main effects, and treatment main effects, in addition to the random effects of subjects within treatment sequence groups.

The secondary outcomes, changes in VAS ratings from time 0 to 30, 60, 120, 180, and 240 minutes following the start of the breakfast meal, were analyzed using a mixed model analysis of variance for a doubly repeated measures crossover trial where the first repeated measures variable was the test day and the second variable was elapsed time since the start of breakfast. The changes from time 0 were summarized as least squares means plotted for each cereal type across the assessment times, and any baseline differences between VAS scores that existed despite randomization were normalized to zero [24]. Thus, differential treatment effects were compared with respect to AUC and per time point. Area under the curve was estimated using the linear trapezoidal rule and calculated in terms of change from baseline to account for the differences at baseline. Results were summarized as least squares means. The differences in molecular weight, radius of gyration, and the AUC for glucose release were compared using *t* tests. Median viscosities after oral and initial gastric digestion were determined and then compared using *t* tests. Results were summarized as mean  $\pm$  standard deviation. The significance level under the null hypothesis was set at  $\alpha = 0.05$  and the levels quoted are 2-sided. All analyses were performed using SAS 9.2 (SAS Institute, Cary, NC).

During the planning phase of the study, sample size was estimated using G\*Power, Version 3.1.2 (F. Faul, Universitat Kiel, Germany). The study was sufficiently powered with 46 participants for detecting a minimum difference of 1258 mm  $\times$  min between cereal types, which is similar to observed differences in AUC (1,213 mm  $\times$  min) for desire to eat from a similar study that assessed appetite sensations [29].

## **RESULTS**

Forty-eight subjects (29 females and 19 males) were enrolled in the study. One subject who determined she was pregnant was excluded before completion of the study. Six participants were obese (BMI  $\geq 30$ ), 13 were overweight (BMI  $\geq 25$ ), 26 were of normal weight (BMI 18.5–24.9), and

**Table 1.** Characteristics at Baseline of 48 Participants Enrolled in the Study Evaluating the Effect of Oat-Based Products on Satiety and Included in the Mixed Model Analysis

	Mean	SD	Range
Age (years)	32.5	11.1	19–63
Height (cm)	168.9	9.1	153.3–190.2
Weight (kg)	71.2	16.7	46.8–112.8
BMI (kg/m <sup>2</sup> )	24.9	5.0	16.6–38.7
Waist circumference <sup>a</sup> (cm)	82.0	13.9	63.1–124.2

BMI = body mass index.

<sup>a</sup>One missing value.

3 were underweight (BMI < 18.5). Data relating to all enrolled participants were included in the mixed model analysis. There were no adverse events. Descriptive characteristics of the subjects at baseline are summarized in Table 1. A nutrient analysis of the breakfast meals including the  $\beta$ -glucan content of the cereals that was measured in the study is presented in Table 2.

### Hunger and Fullness

The reduction in hunger was significantly greater after consuming oatmeal compared to the RTEC based on the AUC analysis (oatmeal: 10,615 ± 727.15 mm × min versus RTEC: 8,472.10 ± 733.92 mm × min,  $p = 0.005$ ). Reductions in hunger were larger after consuming oatmeal compared to RTEC at 120 minutes ( $p = 0.005$ ), 180 minutes ( $p < 0.001$ ), and 240 minutes ( $p = 0.012$ ; Fig. 1A). Increase in fullness was significantly greater after consuming oatmeal compared to the RTEC based on the AUC analysis (oatmeal: 11,486 ± 708.67 mm × min versus RTEC: 9,442.54 ± 716 mm × min,  $p = 0.001$ ). The increase was greater after consuming oatmeal compared to the RTEC at 120 minutes ( $p = 0.019$ ), 180 minutes ( $p = 0.002$ ), and 240 minutes ( $p = 0.049$ ; Fig. 1B).

**Table 2.** Energy and Nutrient Content of Breakfast Meals Obtained from Product Information, Except  $\beta$ -Glucan Content, Which Was Measured

	Quaker Instant Oatmeal <sup>a</sup>	Honey Nut Cheerios <sup>b</sup>	Lactose-Free, Fat-Free Milk
Energy (kcal)	250	250	112.5
Fat (g)	5.01	3.41	0
Protein (g)	8.35	4.54	10
Total carbohydrates (g)	45.09	49.97	16.25
Total fiber (g)	6.68	4.54	0
Soluble fiber (g)	3.34	1.84	0
$\beta$ -Glucan (g)	2.68	1.73	0
Sugar (g)	1.67	20.43	15
Sodium (mg)	0	363.43	156.25
Serving size (g)	66.8	63.6	307

<sup>a</sup>Quaker Oats (Pepsico Inc., Barrington, IL).

<sup>b</sup>Honey Nut Cheerios (General Mills Inc., Minneapolis, MN).

### Desire to Eat and Prospective Intake

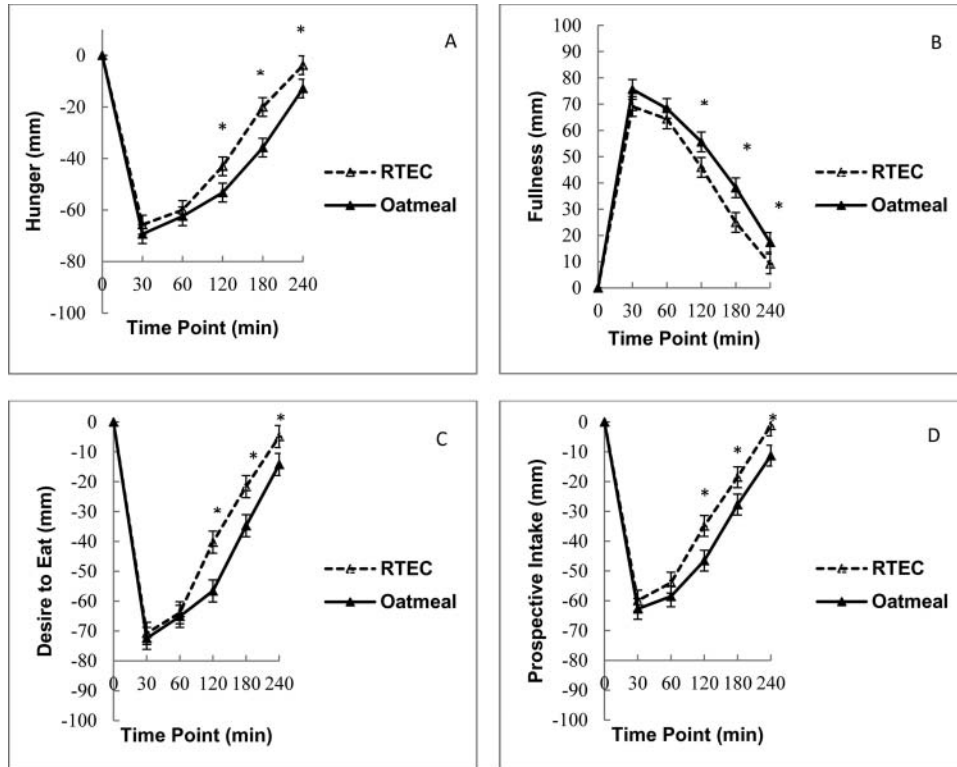
Reduction in the desire to eat was significantly greater after consuming oatmeal compared to the RTEC, based on the AUC analysis (oatmeal: 11,010 ± 730.57 mm × min versus RTEC: 8,854.71 ± 735.40 mm × min,  $p = 0.001$ ). The reduction was greater after consuming oatmeal compared to the RTEC at 120 minutes ( $p < 0.001$ ), 180 minutes ( $p < 0.001$ ), and 240 minutes ( $p = 0.007$ ; Fig. 1C). A similar reduction in prospective food intake was determined after consuming oatmeal compared to the RTEC, based on the AUC analysis (oatmeal: 9,310.79 ± 717.41 mm × min versus RTEC: 7,372.97 ± 723.08,  $p = 0.006$ ). The reduction was greater after consuming oatmeal compared to the RTEC at 120 minutes ( $p < 0.001$ ), 180 minutes ( $p = 0.004$ ), and 240 minutes ( $p = 0.002$ ; Fig. 1D).

### Energy, Food, and Macronutrient Intake

The food intake results were analyzed with and without intakes from the beverages. Results from both the analyses were similar; hence, results of the food intake without the beverages are presented. Energy (kcal) intake at the *ad libitum* lunch meal was significantly lower (difference = 85 kcal,  $p = 0.012$ ) following consumption of the oatmeal compared to the RTEC breakfast meal. Fat ( $p = 0.02$ ) and protein ( $p < 0.001$ ) intake were significantly lower after eating oatmeal, whereas carbohydrate intake and total weight of food consumed were not significantly different between the 2 conditions (Figs. 2 and 3).

### In vitro Analyses

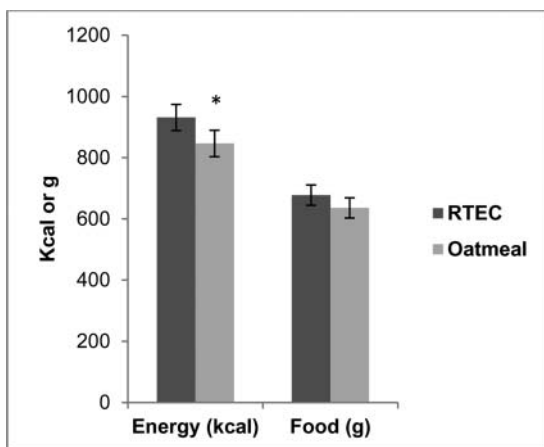
The *in vitro* kinetics of starch digestion based on glucose release showed no differences between the 2 breakfast products (oatmeal: 99 ± 3 g × min, RTEC: 98 ± 2 g × min,  $p > 0.05$ ). The molecular weight of the  $\beta$ -glucan in oatmeal was higher than that of the RTEC (oatmeal: 3.89 × 10<sup>5</sup> ± 8.96 × 10<sup>3</sup> Da, RTEC: 2.21 × 10<sup>5</sup> ± 4.16 × 10<sup>3</sup> Da,  $p < 0.001$ ). Additionally,



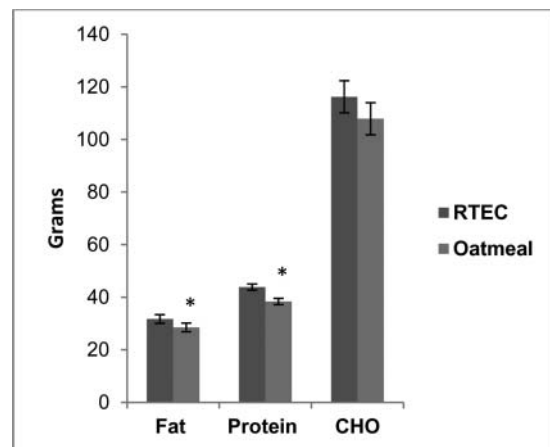
**Fig. 1.** Visual analog scale ratings ( $n = 48$ ) before and after consumption of oatmeal and an RTEC. Oatmeal increased satiety across all measures: (A) Hunger ratings: \*Differences in least squares means (LSM) were significantly different at 120 minutes ( $p = 0.005$ ), 180 minutes ( $p < 0.001$ ), and 240 minutes ( $p = 0.012$ ). (B) Fullness ratings: \*Differences in LSM were significant at 120 minutes ( $p = 0.019$ ), 180 minutes ( $p = 0.002$ ), and 240 minutes ( $p = 0.049$ ). (C) Desire to eat ratings: \*Differences in LSM were significant at 120 minutes ( $p < 0.001$ ), 180 minutes ( $p < 0.001$ ), and 240 minutes ( $p = 0.007$ ). (D) Prospective food intake ratings: \*Differences in LSM were significant at 120 minutes ( $p < 0.001$ ), 180 minutes ( $p = 0.004$ ), and 240 minutes ( $p = 0.002$ ). Values are mean  $\pm$  standard error.

the  $\beta$ -glucan molecules in oatmeal, once hydrated, formed larger spheres than the  $\beta$ -glucan molecules in the RTEC. The radius of gyration of the  $\beta$ -glucan molecules in oatmeal measured as  $50.23 \pm 0.76$  nm was greater ( $p < 0.001$ ) than that of the RTEC measured at  $36.83 \pm 0.42$  nm (Figs. 4A and 4B).

Oatmeal exhibited a higher viscosity than the RTEC after oral and initial gastric digestion (oatmeal median viscosity: 7,220.5, interquartile range: 2,816.5–12,154.5 cP; RTEC median viscosity 140.0, interquartile range: 131.5–254.0 cP;  $p = 0.025$ ; Fig. 5).



**Fig. 2.** Energy and food intake at lunch meal following consumption of RTEC and oatmeal at breakfast ( $n = 48$ ). Values are mean  $\pm$  standard error. Asterisk indicates a significant difference ( $p = 0.012$ ).



**Fig. 3.** Macronutrient intake at lunch meal following consumption of RTEC and oatmeal at breakfast ( $n = 48$ ). Values are mean  $\pm$  standard error. Asterisks indicate a significant difference ( $p < 0.05$ ).

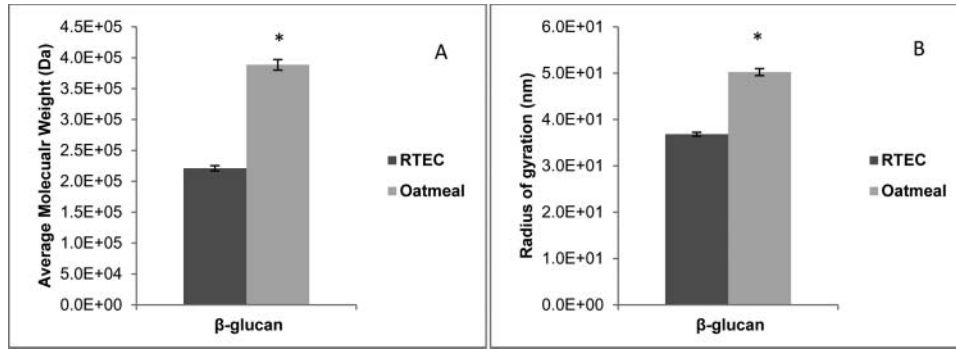


Fig. 4. (A) Average molecular weight (Mw) in Daltons (Da) and (B) radius of gyration in nanometers (nm) of the  $\beta$ -glucan content of oatmeal and the RTEC. \*Both outcomes were significantly different at  $p < 0.001$ . Values are mean  $\pm$  standard deviation.

## DISCUSSION

In this study, the viscosity of 2 oat-based cereals was measured and its effects on satiety were evaluated. Consistent with the hypothesis, a breakfast meal consisting of oatmeal increased fullness and suppressed hunger, desire to eat, and prospective intake, resulting in a reduction in energy intake at lunch, compared to an oat-based RTEC. The content, molecular weight, and radius of gyration of the  $\beta$ -glucan in oatmeal were higher than that of the  $\beta$ -glucan in the RTEC, which most likely contributed to the higher viscosity generated by oatmeal.

In order to form a viscous solution,  $\beta$ -glucan must be sufficiently solubilized. Thus, the difference in the hydration levels of  $\beta$ -glucan in these 2 oat-based cereals may have played an important role. Oat-soluble fiber imbibes water, swells, and gradually dissolves at ambient or higher temperatures [30]. The instant oatmeal used in this study consisted of thin-cut flakes that hydrated easily after adding boiling water. In contrast,  $\beta$ -glucan in the RTEC prepared with cold milk did not

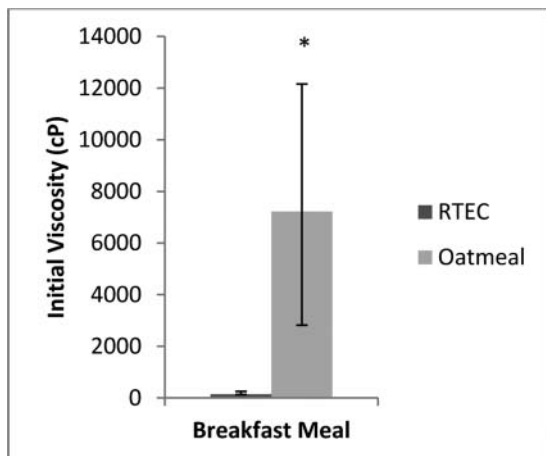


Fig. 5. Median viscosities of oatmeal and RTEC meals after oral and initial gastric digestion observed in the *in vitro* study. Viscosity values are the median of 3 replicates and expressed in centipoise (cP)  $\pm$  interquartile range. Asterisk indicates a significant difference ( $p = 0.03$ ).

hydrate as easily. This may have contributed to its lower viscosity and may explain why the difference in the viscosity of the 2 cereals was greatest when they first entered the stomach as estimated in the *in vitro* simulation. Although during transit through the gastrointestinal tract,  $\beta$ -glucan in the RTEC might be solubilized and finally hydrated completely, the initial high viscosity of oatmeal seemed to be important for its effects on satiety. The importance of initial viscosity was also demonstrated in a previous study comparing instant oatmeal, old-fashioned oatmeal, and the RTEC. Instant oatmeal displayed greater initial viscosity than old-fashioned oatmeal and produced greater satiety than old-fashioned oatmeal when both were compared with the RTEC [20].

Consistent with research indicating that people tend to consume a constant weight of food [31], in the present study the weight of food consumed at lunch did not differ between the 2 conditions. Although the carbohydrate intake did not differ, the fat and protein intake at the lunch meal were lower after consumption of the oatmeal breakfast compared to the RTEC, which resulted in a reduction in energy intake.

A sensory evaluation of the 2 breakfast meals was not conducted in this study to determine the palatability of the 2 test meals. Palatability is a momentary evaluation liable to change with the experience [32], and it appears to affect satiation (meal termination) more than satiety (prolongation of the interval between meals) [33]. In one study, preloads of beef consommé (10 kcals) varying in their rated palatability reduced appetite compared to a no soup control, but palatability had no effect on appetite ratings. Energy intake at a subsequent meal was not different among the conditions, but the energy content of the soup may have been too low to affect subsequent food intake, indicating that sensory stimulation alone is insufficient to reduce energy intake [34]. In another study, although palatability of a preload test meal affected appetite ratings, there was no effect on subsequent food intake [35].

The nutrient composition of the breakfast cereals was not matched, but the purpose of the study was to determine whether oatmeal would be a good replacement for a ready-to-eat cereal to keep consumers full for a prolonged period.

Among the macronutrients, protein-induced satiety in the short term is well documented; however, the effects on food intake are less consistent [36,37]. The difference in the protein contents of the meals or diets evaluated in studies that demonstrated protein-induced satiety ranged from 15% to 25% of the energy content [38–42]. In the present study, the difference in the protein contents of the breakfast meals (4%) was less than the proportion that has been shown to facilitate increased satiety.

The RTEC had higher sugar content than oatmeal. Instant oatmeal is composed of thinly cut flakes, which facilitates quick hydration during cooking and increases the rate of digestion and absorption. It has been shown to have a high glycemic index [43] and the *in vitro* studies examining the kinetics of starch digestion and glucose release showed that there was no difference between the 2 cereals. However, *in vitro* studies do not reflect effects such as gastric motility and nutrient interactions. Hence, it is likely that the glycemic indices of the 2 products differed. Nevertheless, studies that investigated the effect of the glycemic response on satiety have shown inconsistent results [44–47]. Thus, based on the results of the *in vitro* studies, the fiber content of oatmeal, especially the  $\beta$ -glucan component, appears to be the most likely factor influencing appetite, satiety, and subsequent food intake.

Dietary guidelines emphasize consumption of whole grain foods to increase intake of dietary fiber [48]. Both products tested in this study meet that description. However, foods that enhance satiety offer quick gratification. Cues that have a reward associated with them, once learned, trigger motivational wanting to secure these rewards [49]. When that cue is consumption of a food and the reward is a predicted level of satiety, it can have significant effects on the regulation of food intake and energy balance. Unlike other health promoting foods, the time frame to learn the association between consumption of the food and increase in satiety is short and the effects are easily monitored by the consumer, which can greatly facilitate the learned association [50]. Even so, the crux of the issue is whether wanting can be sustained with repeated exposure. Nevertheless, foods that increase satiety provide consumers with appetite control strategies, especially those susceptible to the wiles of an obesogenic environment. Foods that increase satiety also help to cope with mood states provoked by restricted energy intakes, facilitate compliance with healthy eating goals, and promote adherence to diet restrictions.

The main limitation of this study was that the macronutrient composition of the cereals was not matched; hence, it is possible that differences in the protein and sugar content, although insignificant in their individual effects, may have exerted a cumulative effect on satiety. Further, it is possible that prior perceptions about the satiating properties of the cereals may have influenced the results. *In vivo* measurements of  $\beta$ -glucan viscosity might have provided a better understanding of the satiating effects of oat-based cereals; however, these

measurements are difficult to obtain. Though *in vitro* models may fall short of the dynamic environment of the gastrointestinal tract, the conditions can be standardized and provide a means for understanding physiological events.

It would have been interesting to compare treatments in subgroups, but there must be a sufficient number of participants within the subgroups to support making valid conclusions from such analyses. The crossover design justified investigating the primary outcome in a diverse sample; however, it did not provide adequate power to enable drawing reliable conclusions from subgroup analyses. The strength of this study is that the physicochemical properties of  $\beta$ -glucan were analyzed and appeared to corroborate the satiety response.

## CONCLUSIONS

The effects of instant oatmeal on satiety demonstrated in this study are similar to the effects that were observed in previous studies comparing the satiety effects of a thicker oat flake (old-fashioned oatmeal) with the oat-based RTEC [19] and a smaller serving of instant oatmeal to an isocaloric serving of the RTEC [20]. In addition, energy intake was reduced following consumption of instant oatmeal compared to the RTEC. The results of this study add to the evidence provided through a multistep proof of concept that oatmeal suppresses appetite, increases satiety, and reduces subsequent energy intake. The hydration and physicochemical properties of  $\beta$ -glucan are important factors influencing viscosity, a rheological property of soluble fibers that is thought to mediate satiety. Oatmeal could replace foods in the diet and keep consumers full for a prolonged period. Thus, as a satiety-enhancing product, oatmeal appears to be a food that merits investigation.

## FUNDING

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## CONFLICT OF INTEREST

Marianne O'Shea, Nicolas Bordenave, B. Jan Willem van Klinken, and YiFang Chu are employees of PepsiCo R&D Nutrition. Candida Rebello, Corby Martin, William Johnson, Hongmei Han, and Frank Greenway have no conflict of interest.

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