Greater satiety response with resistant starch and corn bran in human subjects

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Received 24 November 2008; revised 16 January 2009; accepted 20 January 2009

Abstract

Some studies suggest high-fiber foods are more satiating than foods with little or no fiber. However, we hypothesized that certain types of dietary fiber may enhance satiety more than others. Healthy men and women (N = 20) participated in this acute, randomized double-blind, crossover study comparing the effects of 4 fibers and a low-fiber (LF) treatment on satiety. On 5 separate visits, fasting subjects consumed either a LF muffin (1.6 g fiber) or 1 of 4 high-fiber muffins (8.0-9.6 g fiber) for breakfast. The subjects used 4 questions on 100 mm visual analogue scales to rate satiety at baseline and at regular intervals for 180 minutes after muffin consumption. Responses were analyzed as area under the curve and significant differences from baseline. Satiety differed among treatments. Resistant starch and corn bran had the most impact on satiety, whereas polydextrose had little effect and behaved like the LF treatment. Results from this study indicate that not all fibers influence satiety equally.

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Keywords: Satiety; Fiber; Visual analogue scale; Appetite; Hunger

Abbreviations: AUC, area under the curve; BG, barley β-glucan + oat fiber; CB, corn bran; LF, low fiber; RS, resistant starch; VAS, visual analogue scales.

1. Introduction

Foods high in fiber may influence satiety and ultimately body weight regulation [1-3]. A review of studies examining the effects of fiber on body weight found that higher dietary fiber intake was associated with increased satiety and decreased hunger [4]. The proposed mechanisms for this relationship remain unclear, but the type of fiber may play a role.

In the gut, certain soluble fibers form a viscous gel matrix that is believed to slow gastric emptying and lead to a greater feeling of fullness [3,5]. As well, some viscous fibers slow absorption of glucose in the small intestine and lead to lower postprandial glycemic and insulinemic responses [6-8]. Both of these mechanisms are postulated to increase satiety. Some studies also report satiety improves after consumption of insoluble fiber; however, the mechanism is less clear [9,10]. Insoluble fiber has limited effects on gastric emptying and absorption in the small intestine, but it may be partially fermented in the large intestine. Research on resistant starch (RS) and satiety is sparse and inconsistent [11-13].

In addition, some research suggests that fiber-rich foods may influence satiety through increased mastication or changes in gut hormones (ie, ghrelin or glucagon-like peptide-1) [14-17].
Dietary fiber in foods is a diverse substance and is associated with many bioactive compounds. As well, when functional fibers or isolated fibers are added to foods, they may be soluble, insoluble, fermentable, or viscous—all of which could impart other properties to a food. Thus, it is likely that different types of fiber will not impact satiety uniformly.

Many new types of fiber have been added to the United States food supply since the year 2000 [18]. The addition of fiber to many manufactured foods likely comes in response to claims that fiber may increase satiety and decrease body weight. However, few studies have compared the satiety response of different fibers in the same subject population.

We hypothesized that certain dietary fibers would enhance satiety more than others. To test this hypothesis, we evaluated and compared the satiety response from 5 different muffins. Four muffins contained approximately 9 g of fiber from 4 different sources, and 1 muffin contained approximately 1 g of fiber. Insight into how different types of fiber influence short-term satiety could provide useful information for designing future research, especially studies that wish to evaluate long-term appetite control, food intake, changes in appetite-regulating hormones, and body weight.

2. Methods and materials

In this randomized crossover study, we compared a low-fiber (LF) muffin and 4 high-fiber muffins containing different types of fibers—corn bran (CB), barley \(\beta\)-glucan + oat fiber (BG), RS, and polydextrose. These fibers were chosen for their diverse representation of soluble, insoluble, and RS characteristics, as well as for their ability to be baked uniformly in muffins.

2.1. Subjects

The University of Minnesota Institutional Review Board Human Subjects Committee approved all aspects of this research. Participants were recruited by posters placed around the University of Minnesota campus. Subjects were screened over the telephone and were invited into the study if they met inclusion criteria. Eligible subjects were English speaking, healthy men and women between 18 and 65 years old with a body mass index less than 30. Subjects were excluded if they smoked, had a history of disease, had gastrointestinal conditions affecting digestion and absorption, or if they took medications. Other exclusions included pregnancy, lactation, and recent weight change. Before study commencement, subjects were instructed to maintain current eating and exercise habits and not to initiate any programs that would alter body weight.

2.2. Study visits

On 5 separate occasions, fasted subjects consumed 1 of 4 high-fiber muffins (8.0-9.6 g fiber) or a LF muffin (1.6 g fiber). Visits were held from 6:30 am to 9:30 am on weekdays and were at least 1 week apart. Women participated only during the follicular phase of their menstrual cycle so some visits were 2 to 3 weeks apart.

On the morning of each visit, subjects completed 4 baseline visual analogue scales (VAS) to assess satiety. After the initial VAS were collected, subjects were given their treatment muffin and were instructed to consume it within 10 minutes. They were allowed to drink 540 mL of bottled water, black decaffeinated tea, or black decaffeinated coffee during each visit. The type and amount of beverage was kept consistent at all 5 visits.

Additional satiety VAS were completed at 15, 30, 45, 60, 120, and 180 minutes after baseline. Subjects also completed 5 VAS to assess muffin palatability at 15 minutes. During the 180-minute visits, subjects were seated in a quiet room and were allowed to read, use laptop computers, work quietly, or listen to music. Physical conditions and location of the room were consistent for all visits.

2.3. Muffin descriptions and fiber types

All 5 muffins were similar in appearance and had nearly identical macronutrient content (see Table 1). They were prepared using a quick-bread muffin recipe, which varied by fiber type. All fibers were commercially available (CB, J.R. Short Milling, Kankakee, Ill; Bleached Oat Fiber, SunOpta, Bedford, Mass; Barley \(\beta\)-glucan, Cargill, Minneapolis, Minn; Novelose 330 and Hi-Maize 260, National Starch, Bridgewater, NJ; Polydextrose, Danisco, Copenhagen, Denmark).

After baking and cooling, the muffins were frozen at \(-20^\circ\) C. Muffins were removed from the freezer 12 hours before each subject visit and were thawed in a sealed container at room temperature.

### Table 1

Muffin composition

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Total fiber (g)</th>
<th>Insoluble fiber (g)</th>
<th>Soluble fiber (g)</th>
<th>Energy (kJ)</th>
<th>Fat (g)</th>
<th>Pro (g)</th>
<th>Sugar (g)</th>
<th>Weight (g)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>1.6</td>
<td>1.1</td>
<td>0.4</td>
<td>745</td>
<td>2.9</td>
<td>3.9</td>
<td>13.2</td>
<td>76</td>
<td>39</td>
</tr>
<tr>
<td>RS</td>
<td>8.0</td>
<td>7.9</td>
<td>0.1</td>
<td>729</td>
<td>3.3</td>
<td>3.8</td>
<td>14.2</td>
<td>92</td>
<td>47</td>
</tr>
<tr>
<td>BG</td>
<td>9.4</td>
<td>5.3</td>
<td>4.0</td>
<td>733</td>
<td>3.0</td>
<td>3.5</td>
<td>13.7</td>
<td>96</td>
<td>47</td>
</tr>
<tr>
<td>Polydextrose</td>
<td>9.5</td>
<td>1.3</td>
<td>8.8</td>
<td>741</td>
<td>2.9</td>
<td>3.5</td>
<td>14.2</td>
<td>89</td>
<td>38</td>
</tr>
<tr>
<td>CB</td>
<td>9.6</td>
<td>9.1</td>
<td>0.5</td>
<td>729</td>
<td>3.5</td>
<td>4.0</td>
<td>13.5</td>
<td>99</td>
<td>43</td>
</tr>
</tbody>
</table>

* Fiber content was analyzed using standard Association of Analytical Communities (AOAC) methods. Analysis was completed at Medallion Labs, Minneapolis, Minn.
2.4. Visual analogue scales

Satiety was evaluated using questions from a previously validated 100 mm VAS [19]. Questions were taken directly from the original citation: hunger—How hungry do you feel? Not hungry at all (0 mm) vs I have never been more hungry (100 mm); satisfaction—How satisfied do you feel? I am completely empty (0 mm) vs I cannot eat another bite (100 mm); fullness—How full do you feel? Not at all full (0 mm) vs totally full (100 mm); prospective food intake—How much do you think you can eat? Nothing at all (0 mm) vs a lot (100 mm).

Five characteristics were used to assess the palatability of each muffin. Visual appeal, smell, taste, and overall pleasantness were scored as good (0 mm) vs bad (100 mm). Aftertaste was scored as much (0 mm) vs none (100 mm).

2.5. Statistical analyses

The primary outcome was area under the curve (AUC) for responses on the VAS. The AUC was calculated by the trapezoidal rule. The fiber treatments were compared by each AUC for hunger, satisfaction, fullness, and prospective food intake using a mixed effects linear model with a random subject effect (Proc Mixed). Analytic models were reduced to include only 2 variables, treatment and visit number (carryover, palatability characteristics, and interaction terms were tested and eliminated). Pairwise comparisons were used to compare treatment means. Data are presented as mean AUC value ± SEM.

Paired t tests were used to calculate the length of time each VAS response remained significantly different from baseline; this was used to estimate duration of satiety. Data are presented as the number of minutes that each feeling differed significantly from the baseline feeling response value. Significance was determined by 2-sided tests with \( P < .05 \). Statistical analysis was performed with SAS version 9.1.2 [20].

3. Results

Twenty subjects (7 men and 13 women) completed all 5 visits. Mean body mass index ± SEM was 24.5 ±0.7 (range, 21.9-26.7) and 22.9 ±0.6 (range, 19.7-26.9) for men and women, respectively. Mean age ±SEM for the men was 28 ±4 (range, 20-54) and 24 ±2 (range, 18-50) for women. At baseline, there were no statistically significant differences among scores on the VAS.

3.1. Differences among treatments

Fig. 1 compares the mean AUC scores (for hunger, prospective food intake, satisfaction, and fullness) among treatments.

Satiety measures differed among treatments. AUC\textsubscript{Hunger} suggests that subjects were less hungry after eating CB (\( P = .056 \)) or RS (\( P = .06 \)) than after eating the LF muffin. AUC\textsubscript{Prospective food intake} was also lower among the same treatments. Corn barn and RS stimulated less desire for food intake than the LF treatment (\( P = .025 \) and \( P = .009 \), respectively). AUC\textsubscript{Satisfaction} and AUC\textsubscript{Fullness} were higher after CB than after either the LF or polydextrose treatments (\( P < .049 \)).

AUC\textsubscript{Satisfaction} was also marginally higher after RS than after either LF or polydextrose (\( P = .08 \)).

In general, the AUC analysis suggests that CB and RS were more satiating than both the LF and polydextrose treatments.

3.2. Duration of satiety for individual fibers

Each treatment influenced satiety-related feelings differently. Fig. 2 shows how long each feeling was influenced (compared to baseline) for the individual fibers. After eating the RS muffin, mean hunger scores remained significantly lower than baseline for 120 minutes; hunger was less than baseline for only 15 minutes after polydextrose. Satisfaction and fullness levels were significantly greater than baseline for 180 minutes after the RS muffin, but for only 60 minutes

![Fig. 1. Mean AUC scores ± SEM for each treatment and each VAS question (N = 20 for each bar). The AUC was calculated by the trapezoidal rule and was compared, in SAS, using a mixed effects linear model with a random subject effect. Within each question, treatments with different letters are significantly different at \( P < .05 \). Treatments with the same letters, or without letters, were indistinguishable from each other.](image-url)
after polydextrose. After CB, hunger was significantly suppressed for 60 minutes, satisfaction was maintained for 120 minutes, and fullness was maintained for 180 minutes.

3.3. Muffin palatability

The taste of the polydextrose muffin was preferred over all other muffins, and overall pleasantness was significantly greater than the CB and RS treatments ($P < .05$). The LF treatment also had greater overall pleasantness than the BG treatment ($P = .03$). However, palatability characteristics did not explain satiety-related feelings when included in the statistical model.

4. Discussion

Satiation and satiety describe the feelings that lead to cessation of a meal and inhibit the desire to eat between meals. Both sensations are regulated by a multitude of environmental, central, and peripheral signals. Unfortunately, satiety cannot be assessed with 1 straightforward question; therefore, multiquestion VAS are commonly used. For the purpose of this study, we determined satiety based on differences among VAS questions about hunger, satisfaction, fullness, and prospective food intake.

Our findings suggest that not all fibers influence satiety equally. Resistant starch and CB were consistently more satiating than the LF treatment; they also influenced the duration of satiety longer than the LF, BG, and polydextrose treatments.

In this study, RS was highly satiating. Eight grams of RS kept subjects significantly less hungry than baseline for 120 minutes and more full and satisfied for the 180-minute test period. Hunger and prospective food intake were also lower after RS compared to the LF treatment. Our findings contradict 2 older studies, which found that RS did not improve satiety compared to a no-fiber control. [23]

Polydextrose was the least satiating. Compared to baseline, polydextrose decreased hunger only 15 minutes, whereas all other treatments significantly decreased hunger for 60 minutes or more. Patterns in the AUC analysis suggest this fiber had little impact on satiety and behaved similar to the LF treatment. In fact, the AUC scores for satisfaction and fullness were identical for the polydextrose and LF treatments, both were 111 and 108, respectively (refer to Fig. 2). Our findings are similar to King et al [23], which reported no differences in satiety when comparing 25 g of polydextrose to a no-fiber control.
Additional studies also suggest that certain types and doses of fiber may influence satiety more than others. Samra and Anderson [9] reported subjects had significantly lower appetite scores after eating 33 g of fiber (corn plus wheat bran) than after 9 g of fiber from white bread. Raben et al [24] found subjects felt significantly more full and had less desire to eat after consuming 25 g of pea fiber baked into wheat bread than after 9 g of fiber from plain wheat bread. And, Burley et al [25] reported a small but significant difference in fullness when comparing how subjects felt after eating 12 or 3 g of fiber.

In contrast, Weikert et al [26] showed no difference in satiety when comparing a no-fiber bread to breads with 10 g of wheat fiber or oat fiber. Likewise, another study reported no difference in mean hunger ratings between 22 g of soluble fiber from psyllium and 22 g of insoluble fiber from wheat bran [27]. Lastly, Levine et al [10] reported no difference in hunger when comparing a no-fiber cereal to cereals with either 11 g of wheat fiber or 39 g of wheat plus CB fiber. However, the same subjects felt significantly less hungry after eating 18 or 35 g of bran cereal fiber than after eating no-fiber cereal [10].

Our results, as part of the bigger body of research, strengthen the notion that fiber plays a role in satiety. However, type and dose of fiber likely play an important role. At this time, it is unclear which types and doses influence satiety the most, although our study suggests RS or CB may be more effective than polydextrose.

The lack of clarity in this relationship may be partly explained by differences in study design, specifically with regard to variations in VAS and the way fiber is administered (ie, as a supplement mixed into liquid, baked into bread, or as part of a whole food like cooked oats).

Furthermore, palatability of a fiber-rich food may also play a role. In our study, RS was highly satiating and the least palatable, whereas polydextrose was the inverse. Although our muffins differed in palatability, these characteristics did not help explain satiety responses when included in the statistical model. This is not surprising and is supported by a review paper, which reports that palatability of a food (or meal) inconsistently influences appetite and satiety [28]. Highly palatable foods may increase or decrease a person’s level of hunger and subsequent food intake—and the effects may not be predictable.

Our study blindly compared the impact of 4 different types of fiber in a macronutrient-matched breakfast. However, this study had a few limitations. This study did not assess ad lib food intake after subjects consumed the treatment muffins. However, previous studies have used the question of “How much do you think you can eat?” to assess prospective food intake [29]. In addition, 2 studies have found that appetite sensations, as reported on VAS, are useful predictors for spontaneous energy intake [30,31]. We did not control for baseline fiber intake; it is possible that subjects with chronically LF intake may respond differently than subjects who routinely consumed more daily fiber. It is also reason-
able to hypothesize that 9 g of fiber was not a large enough dose; perhaps a larger dose would detect more significant satiety differences. However, 9 g is a very practical dose and something the general population could reasonably consume. Higher doses would likely be less practical. In addition, we must consider the impact of a low-calorie breakfast on satiety. It is possible our results were hindered by providing only 175 calories during a 3-hour breakfast period. We may have seen even stronger results if we had offered foods that reached a calorie level equivalent to a typical breakfast.

The results of this study are especially important at a time when so many food products have added functional fibers. Our findings suggest added fibers will not impact satiety uniformly and that the type of fiber must be carefully considered. Understanding ways to control appetite and food intake is critical as obesity rates rise. Thus, any dietary manipulations that could maximize satiety and decrease desire for food intake may be instrumental for helping people achieve and maintain a healthy body weight.

New research should focus on the fiber type when designing studies to evaluate the relationship between dietary fiber and long-term appetite control or body weight regulation. Certain types of fiber may be more effective than others.

In addition, emerging research suggests some foods may simulate changes in appetite-related gut hormones, such as ghrelin, glucagon-like peptide-1, or peptide YY [32]. Little research has been done to see how fiber may influence these hormones. Given our findings, it would be interesting to know if different types of fiber evoke different gut hormone responses.

In conclusion, this study suggests fiber type influences satiety response. We found that polydextrose had limited satiating capabilities and behaved similar to a LF treatment, whereas RS and CB enhanced short-term satiety. Further research is needed, but this study lays important groundwork for future studies. Specifically, studies should be done to determine if fiber-induced satiety is related to subsequent food intake and a healthy body weight.

Acknowledgment

The Bell Institute of Health and Nutrition, General Mills Inc provided a gift in support of this research. We thank Susan Kamper and Fern Panda for their efforts in product development of the muffins and Jill Heier for her time and assistance with research study visits.

References
