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Michelle J. Clark MS & Joanne L. Slavin PhD

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Review Article

The Effect of Fiber on Satiety and Food Intake: A Systematic Review

Michelle J. Clark, MS, Joanne L. Slavin, PhD

Department of Food Science and Nutrition, University of Minnesota, Saint Paul, Minnesota

Epidemiologic studies have shown that fiber intake is associated with a lower body weight. Satiety and energy intake are possible explanations for this effect. The purpose of this study was to recommend fiber types and doses that are effective in reducing appetite and energy intake. A systematic review was conducted using the American Dietetic Association's evidence analysis process as a guide. Studies were identified from PubMed and bibliographies of review articles. Studies measuring appetite, food and/or energy intake with a treatment period of ≤24 hours, a reported fiber type and amount, a low- or no-fiber control, and healthy human participants were included. Forty-four publications were identified, from which 107 treatments were analyzed. Thirty-eight fiber sources were identified. The percentage of treatments that significantly reduced subjective appetite rating compared with the control was 39%. The percentage that significantly reduced food or energy intake was 22%. The satiety-enhancing effects of β-glucan, lupin kernel fiber, rye bran, whole grain rye, or a mixed high-fiber diet were supported in more than one publication. Most fibers do not reduce appetite or energy intake in acute study designs.

Key teaching points:

- Dietary fiber intake is associated with lower body weight in epidemiologic studies.
- Most acute fiber treatments (61%) did not enhance satiety.
- Most acute fiber treatments (78%) did not reduce food intake.
- Neither fiber type nor fiber dose were related to satiety response or food intake.

INTRODUCTION

Foods that increase satiety and reduce food intake may be beneficial in controlling body weight. Data from the National Health and Nutrition Examination Surveys completed in 2007–2008 revealed that 68.0% of Americans were overweight or obese and 33.8% were obese [1]. Excess weight is a major threat to human health in the United States because it increases the risk of many of the major causes of mortality, including heart disease, diabetes, hypertension, stroke, dyslipidemia, and certain cancers [2].

Fiber is defined as the nondigestible carbohydrates and lignin that are intrinsic and intact in plants and the isolated, nondigestible carbohydrates that have beneficial physiological effects in humans [3]. However, fiber can vary widely in structure and physiological function [4]. Though the recommended adequate intake of fiber for adults is between 21 and 38 g/d, the majority of Americans do not meet this recommendation [5].

In epidemiologic studies, higher fiber and whole grain intakes are associated with lower body weights and the prevention of weight gain compared to diets low in fiber and whole grains [6–8]. These effects may be due to enhanced satiety or decreased food intake after fiber consumption, with stomach distention, fermentation, and changes in gut hormones as possible mechanisms of appetite control [9].

Satiety is the condition of being satisfied after an eating episode, preventing the onset of the next meal [10]. Visual analogue scales (VAS) are used to assess subjective satiety and appetite sensations [11], and *ad libitum* meals and food records are among methods used to evaluate food and energy intake. VAS satiety measures have been shown to be reproducible and sensitive to experimental manipulation in validation studies

Address correspondence to: Joanne L. Slavin, Department of Food Science and Nutrition, University of Minnesota, 225 FScN, 1334 Eckles Ave., Saint Paul, MN 55108. E-mail: jslavin@umn.edu

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[11–14], but not all studies have found agreement between appetite ratings and food or energy intake [11, 12, 15, 16].

The purpose of this review is to investigate the short-term effects of fiber and fiber-containing foods on satiety and food intake. Previous reviews reported that satiety was enhanced and food intake was reduced after consumption of a fiber treatment in most studies [9, 17, 18]. However, the reviews did not choose studies in a systematic way and did not examine possible influencing factors, such as fiber type, study length, or fiber dose. Therefore, a systematic review was conducted to more clearly understand the role of fibers and define recommendations for intake and appetite control. To accomplish this, 2 questions were asked to assess appetite: "What is the acute effect of consuming fiber-containing foods and beverages on (1) VAS satiety ratings and (2) food and energy intake when compared to low- or no-fiber control in healthy adults with particular focus on fiber type and amount?"

METHODS

Literature Search

A systematic literature review was conducted to determine the short-term effect of fiber consumption on satiety and food intake in healthy adults. To prevent bias in study selection, the American Dietetic Association's evidence analysis process was used as a guide [19]. Two questions were developed using the Population, Intervention, Comparison, Outcomes (PICO) method [20]: "What is the effect of consuming fiber-containing foods and beverages on (1) VAS satiety ratings and (2) food and energy intake when compared to low- or no-fiber products in healthy adults with particular focus on fiber type and amount?" Studies were identified via PubMed on July 9, 2010, using the search terms (fibre OR fiber OR "whole grain") AND (appetite OR hunger OR satiety OR fullness OR satiation) and limited to include only human studies in the English language.

Inclusion and Exclusion Criteria

Once the initial search was performed, each article was examined for relevance and quality. Studies were excluded as not relevant to the research questions if there was no fiber value included for fiber-containing food or beverage intervention, no satiety or food intake measure, or non-adult subjects. Because of improvements made in satiety and food intake methodology in recent years, studies published prior to 1995 were excluded. In addition, if the participants had a condition or disease such as diabetes or hypertension the study was excluded. In the second level of evaluation, studies were included if abstracting revealed that the treatment and follow-up duration was 24 hours or less, fiber source and dose were reported, treatments were randomized and appropriately controlled, VAS scales were used to measure appetite sensations, and measurements of food and energy intake were determined by valid methods that were described in the publication. Review articles identified in the PubMed search were examined for additional references, which were evaluated using the criteria described above.

Data Extraction and Analysis

Many studies selected for inclusion were designed to compare multiple fiber types, fiber amounts, treatment durations, study populations, or other factors and therefore contain several treatments. This review will describe results in terms of treatments rather than publications. However, the number of publications is also provided to give further support to the results that were found by multiple investigators.

To describe the effect of the fiber treatments on VAS satiety or food/energy intake measures, levels of efficacy were established: 75%–100%, 50%–74%, 25%–49%, 1%–24% benefit, no effect, mixed no/negative effect, and negative effect. Percentage benefit was calculated as the percentage of VAS questions or food or energy intake measures that were significantly more beneficial than the control. A treatment fiber was said to have no effect if none of the measurements were significantly different than the control. Furthermore, when the treatment led to significantly greater appetite or intake measures than the control, it was considered a negative effect. Finally, a designation of mixed no/negative effect was given when at least one measure gave a negative effect and no other significant differences existed.

Various statistical approaches to reporting satiety and energy intake data were seen in the studies. VAS satiety ratings were reported as area under the curve (AUC), mean, individual time points, composite appetite score, or a combination of these. If AUC was reported, it was the only data point used in our analysis. If AUC was not reported, all other methods were given equal weight. Food and energy intake were reported as intake during an *ad libitum* meal or intake during the remainder of the day using food records. If both methods of measuring food or energy intake were used in a study, they were given equal weight when calculating the overall effect of fiber on food or energy intake. Food intake was reported in the studies as kilocalories and/or grams. Grams of food consumed were only used if kilocalories were not reported.

Results were stratified by fiber type, fiber dose, VAS collection period, *ad libitum* meal time, VAS questions, methods of measuring food intake, and subject body mass index (BMI) to determine the possible influences of these factors. Because the results of this review are presented as significant differences from the controls, it was necessary to calculate fiber dose in each study as the difference between the amount of fiber in the treatment of interest and the amount in the no- or low-fiber control. All reported added fiber, intact fiber, and resistant starch were used in the determination of fiber dose.

RESULTS

Three hundred publications were identified in the PubMed search, of which 74 were review articles, meta-analyses, hypotheses, and letters to the editor and 226 were primary research articles. As shown in Fig. 1, 101 primary research articles were relevant to the research questions, including 79 articles from the PubMed search and an additional 22 relevant articles found by searching the references lists of the 74 reviews, meta-analyses, hypotheses, and letters to the editor. Of all 101 relevant publications, 44 met criteria for quality and were included in the analysis. Within the 44 publications selected for inclusion, 107 individual treatments were identified. All treatments measured satiety and 55 measured food and/or energy intake.

Of the 107 treatments measuring satiety, a strong beneficial effect (75%–100%) was demonstrated by 16 treatments, 50%–74% by 6, 25%–49% by 9, 1%–24% by 11, no effect by 63, and a mixed no/negative effect by 2 (Table 1). In the 55 treatments with food intake as an outcome, 12 had 75%–100% benefit, 41 had no effect, 1 had a mixed no/negative effect, and 1 had a negative effect. Of note, few treatments resulted in a negative effect for either satiety or food intake.

Satiety vs. Food Intake

The reported effect of fibers on VAS satiety ratings did not often correspond to food intake when a beneficial effect was shown for either measure. For example, resistant starch and Fiber One displayed a lack of benefit on VAS satiety ratings but an effect on food and energy intake. Table 2 shows the number of treatments for satiety that correspond to each level of benefit for food intake. In treatments where the percentage benefit for satiety was 50% or greater, 6 of 10 demonstrated 100% benefit from food intake and the remainder did not have an effect. However, there was a stronger association when there was no benefit. In treatments with no effect on satiety, 86% also had no effect on food intake. Thus, results for satiety and food intake were generally not consistent.

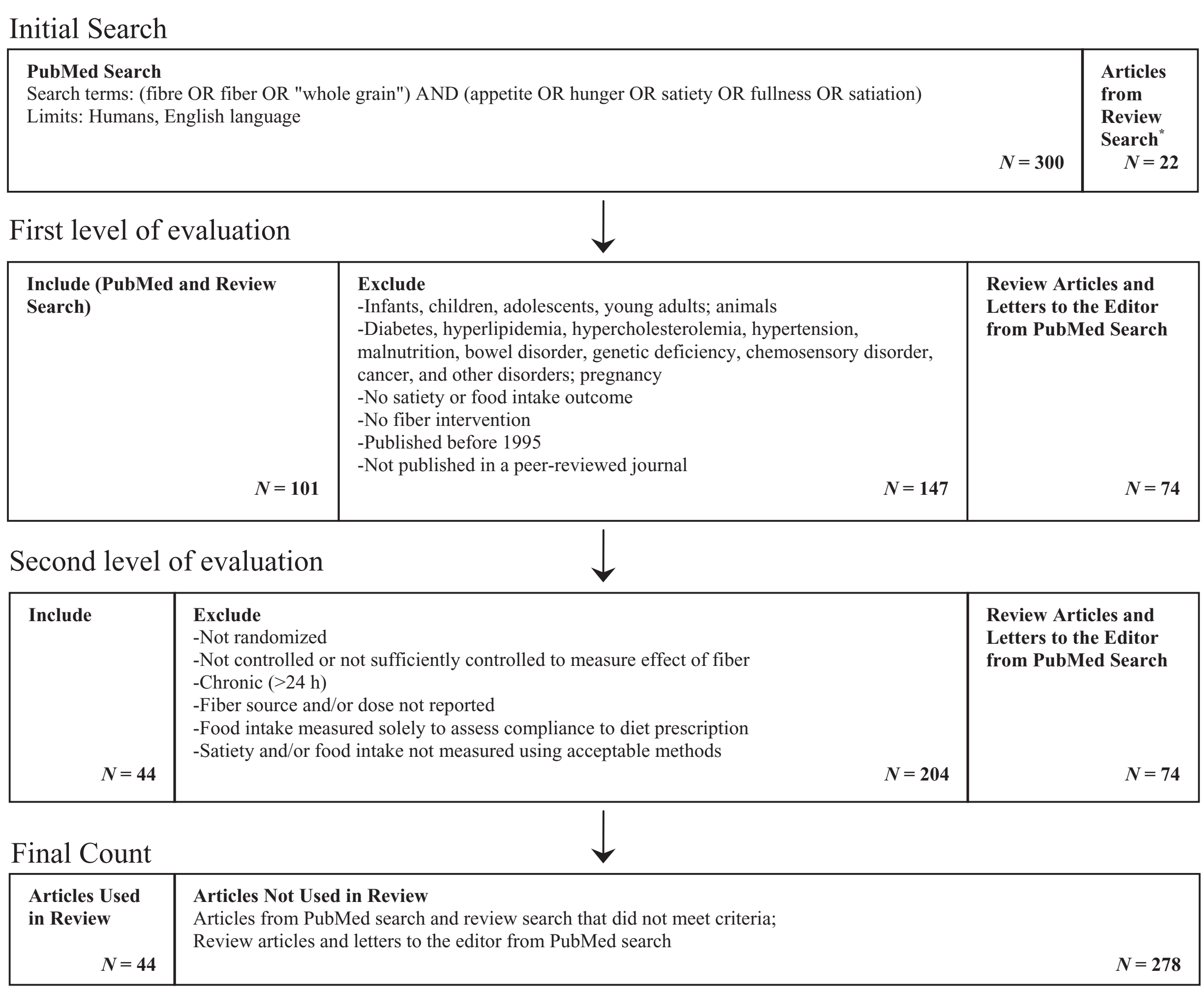

Fig. 1. Search process and selection criteria diagram. *Reference lists of reviews from PubMed search were examined. References that met relevance criteria are included here.

Table 1. Distribution of VAS Satiety and Food/Energy Intake Results for 44 Fiber Studies

				Treatments With Specified% Benefit†						
Outcome	Publications*	Fiber Types	Treatments**	75–100	50–74	25–49	1–24	0	0/N	N
VAS satiety	44	38	107	16	6	9	11	63	2	0
Food/energy intake	25	25	55	12	0	0	0	41	1	1

VAS = visual analogue scale.

*The search revealed a total of 44 articles. All 44 assessed satiety, and a subset of 25 also measured food intake.

**Some publications tested more than one fiber type, fiber dose, or study design.

†1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

Fiber Types

Thirty-eight fiber types were identified with one or more VAS appetite ratings as an outcome. A summary of the effect of different fiber types on satiety is given in Table 3. β-Glucan (from oats and barley), lupin kernel fiber, whole grain rye, rye bran, and a mixed diet of specific fiber-containing foods (5–8 grains, legumes, vegetables, and fruits) demonstrated a benefit in most or all of the treatments. In contrast, psyllium, resistant starch (National Starch Hi-Maize whole grain corn flour, Hi-Maize 260, Hi-Maize 1043 [RS1 & RS2], and Novelose 330 [RS3]), Fiber One (whole grain wheat, corn bran), and wheat bran were not beneficial and in some cases showed a negative effect. The remaining fiber types and foods either did not show conclusive results or were only reported in one publication.

Table 4 shows the distribution of food/energy intake results among 25 fiber types for which food or energy intake was measured. Among fiber types seen in at least 2 publications, Fiber One and resistant starch showed a benefit in more than one treatment but demonstrated no effect in other treatments. In contrast, whole grain barley and psyllium demonstrated no benefit in most treatments and negative effects in others.

Fiber Dose

Fiber dose was determined as described in each included publication, so there were no consistent measurements of fiber in the studies. The fiber value could be the fiber value stated by the manufacturer of a fiber ingredient. Fiber values, especially for the whole food studies, could be the fiber values listed in food composition tables. Different countries rely on different fiber methods for their food composition tables, so studies in the United Kingdom report total unavailable carbohydrate and studies in the United States report total dietary fiber.

When considered independent of fiber type, the effect of fiber dose on appetite is still unclear, as shown in Table 5. For satiety ratings, the ranges of total unavailable carbohydrate with the highest proportion of treatments showing at least 50% benefit were 5.0–7.4 and 10.0–14.9 g. Treatments in the range 15.0–49.9 g showed less benefit. These results were inconsistent with those for food intake, which showed the greatest benefit in the 30.0–49.9 g range.

In a few cases, a greater appetite response was seen from greater doses of treatments from the same fiber source. A dose of 77.1 g high-β-glucan barley showed greater improvements in appetite than a dose of 11.7 g from another study [22, 24]. Fenugreek improved VAS satiety ratings at a dose of 7.2 g but not at 3.6 g [32]. Spinach was effective at improving VAS satiety ratings at 7.3 g but not at 4.4 g, for 2 different particle sizes [63]. For inulin, a dose of 24 g reduced energy intake whereas doses of 6 g, in another study, had no effect on energy intake [33, 34]. Guar gum also enhanced satiety ratings at larger doses. In 2 studies, doses of 5 and 7.8 g enhanced satiety, whereas doses of

Table 2. Comparison of VAS Satiety and Food/Energy Intake Results

			Treatments With Specified Food/Energy Intake Result**			
Satiety% Benefit	Publications	Treatments*	100	0	0/N	N
75–100	6	6	3	3	—	—
50–74	4	4	3	1	—	—
25–49	3	5	—	5	—	—
1–24	3	3	2	1	—	—
0	14	35	4	30	—	1
0/N	1	2	—	1	1	—
N	—	—	—	—	—	—
Total	31	55	12	41	1	1

*Some publications tested more than one fiber type, fiber dose, or study design.

**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

Table 3. Stratification of VAS Satiety Results by Fiber Source

			Treatments With Specified Benefit (%)**					
Fiber Source	Publications	Treatments*	75–100	50–74	25–49	1–24	0	0/N
Barley (β-glucan) [21]	1	1	—	1	—	—	—	—
Barley (WG) [22–26]	5	11	1	—	1	2	7	—
Barley β-glucan + oat fiber [27]	1	1	—	—	—	—	1	—
FOS-barley [25]	1	1	—	—	—	—	1	—
RS-barley [24]	1	1	—	—	—	—	1	—
WG corn + WG soy [28]	1	1	—	—	—	—	1	—
Buckwheat (WG) [29, 30]	2	6	1	—	—	—	5	—
Carrot [31]	1	2	—	1	—	1	—	—
Corn bran [27]	1	1	1	—	—	—	—	—
Fenugreek [32]	1	2	1	—	—	—	1	—
Fructans (FOS) [25]	1	1	—	—	—	—	1	—
Fructans (inulin) [33, 34]	2	3	—	1	—	—	2	—
Guar gum [35–38]	4	5	1	—	1	—	3	—
Liquid fiber [29]	1	1	—	—	1	—	—	—
Lupin kernel [33, 40]	2	2	1	—	1	—	—	—
Mixed diet [41–43]	3	3	1	—	1	1	—	—
Oat (β-glucan) [44]	1	1	—	—	—	1	—	—
Oat (bran) [44, 45]	2	4	—	—	3	—	1	—
Oat (other) [38, 46]	2	2	—	—	—	1	1	—
Oat (WG) [29]	1	4	—	—	—	—	4	—
Pectin [47]	1	1	—	—	—	—	1	—
Polydextrose [27]	1	1	—	—	—	—	1	—
Psyllium [48–52]	5	7	—	1	—	—	5	1
Quinoa [29]	1	2	—	—	—	—	2	—
Resistant starch [24, 27, 53, 54]	4	7	1	—	1	—	5	—
RTEC (All Bran) [55, 56]	2	2	1	—	—	—	1	—
RTEC (Fiber One) [57–59]	4	7	—	—	—	2	5	—
RTEC (Frutta Crunch) [60]	1	2	—	—	—	—	2	—
RTEC (Muesli) [60]	1	2	—	—	—	—	2	—
RTEC (Oatflakes) [55]	1	1	—	—	—	—	1	—
Rye (bran) [61, 62]	2	4	2	—	—	2	—	—
Rye (endosperm) [62]	1	2	—	1	—	—	1	—
Rye (intermediate fraction) [61]	1	3	1	—	—	1	1	—
Rye (WG) [61, 62]	2	3	1	1	—	—	1	—
Spinach [63]	1	4	2	—	—	—	2	—
Wheat (bran) [38, 48]	2	2	—	—	—	—	1	1
Wheat (WG) [64]	2	3	1	—	—	—	2	—
Wheat fiber [46]	1	1	—	—	—	—	1	—
Total	67	107	16	6	9	11	63	2

WG = whole grain; FOS = fructans; RS = resistant starch; RTEC = ready-to-eat cereal.
*Some publications tested more than one fiber type, fiber dose, or study design.
**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

2.5 g in a third and fourth study had no effect [35–38]. Finally, an 18.1 g dose of All Bran enhanced VAS satiety ratings, but a dose of 6 g did not [55, 56]. In contrast to the dose–responses seen among these fiber treatments, there were many fiber types in which a greater dose did not improve appetite.

Fiber Properties

Fiber types known to be largely soluble and viscous are β-glucan (from barley or oats), fenugreek, guar gum, pectin, and psyllium [5, 65]. Lupin kernel fiber is viscous but only partially soluble [66]. Examined together, these fiber types had varying effects on satiety and food intake. Those enhancing satiety were β-glucan and lupin kernel fiber, whereas pectin and psyllium had a minimal effect. β-Glucan from barley or oats led to significantly less energy intake than controls. Lupin kernel fiber had mixed results, whereas fenugreek, guar gum, pectin, and psyllium predominantly had no effect on energy intake.

β-Glucan, guar gum, inulin, fructans (FOS), and resistant starch have been found to be highly fermentable [5], and inulin, FOS, and resistant starch also have prebiotic properties [67]. However, these fiber types did not consistently enhance satiety or reduce food intake. After β-glucan intake, VAS satiety ratings were significantly improved and energy intake was significantly

Table 4. Stratification of Food/Energy Intake Results by Fiber Source

			Treatments With Specified Result**			
Fiber Source	Publications	Treatments*	100	0	0/N	N
Barley (β-glucan) [21]	1	1	1	—	—	—
Barley (WG) [22, 25, 26]	3	3	—	2	—	1
FOS-barley [25]	1	1	—	1	—	—
Buckwheat (WG) [29]	1	4	—	4	—	—
Carrot [31]	1	2	2	—	—	—
Fenugreek [32]	1	2	—	2	—	—
Fructans (FOS) [25]	1	1	—	1	—	—
Fructans (inulin) [33, 34]	2	3	1	2	—	—
Guar gum [37]	1	1	—	1	—	—
Liquid fiber [39]	1	1	—	1	—	—
Lupin kernel [33, 40]	2	2	1	1	—	—
Mixed diet [42]	1	1	—	1	—	—
Oat (β-glucan) [44]	1	1	1	—	—	—
Oat (bran) [44]	1	3	—	3	—	—
Oat (WG) [29]	1	4	—	4	—	—
Pectin [47]	1	1	—	1	—	—
Psyllium [48–50, 52]	4	6	1	4	1	—
Quinoa [29]	1	2	—	2	—	—
Resistant starch [53, 54]	2	5	2	3	—	—
RTEC (All Bran) [56]	1	1	1	—	—	—
RTEC (Muesli) [60]	1	2	—	2	—	—
RTEC (Fiber One) [57–59]	3	4	2	2	—	—
RTEC (Frutta Crunch) [60]	1	2	—	2	—	—
Wheat (bran) [48]	1	1	—	1	—	—
Wheat (WG) [26]	1	1	—	1	—	—
Total	35	55	12	41	1	1

WG = whole grain; FOS = fructans; RTEC = ready-to-eat cereal.

*Some publications tested more than one fiber type, fiber dose, or study design.

**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

lower than after the control treatment. For guar gum, inulin, FOS, and resistant starch, the majority of treatments had no effect on satiety or food intake.

Not reflected in the analysis of the fiber types alone, 4 studies looked at the effect of particle size on satiety and food intake. Nilsson et al. [24] compared bread made from whole barley kernels with bread made from kernels cut 1–2 times. Neither treatment increased satiety relative to the control. Hlebowicz et al. [64] tested bread made from whole kernel wheat and bread made from whole wheat flour containing 5.1 g of unavailable carbohydrate. Satiety was significantly greater than the control for the whole kernel bread but not for the whole wheat flour bread. Anne Moorhead et al. [31] compared whole carrots to blended carrots with 4 g of unavailable carbohydrate as part of a meal. The whole carrots led to a greater number of significant satiety ratings than the blended carrots. Both meals reduced food intake. Finally, Gustafsson et al. [63] tested 2 different sizes of spinach pieces (cut and minced) as part of a meal. Particle size did not affect the number of satiety ratings significantly different from the control when tested at 7.3 and 4.4 g of unavailable carbohydrate.

Study Design

Table 6 shows the percentage benefit for satiety and food intake at different VAS collection end times and *ad libitum* meal times. VAS satiety ratings were significantly enhanced compared to the control more frequently for treatment follow-up completed 3 to 15 hours after ingestion of the fiber treatment than for those completed after less than 3 hours or more than 15 hours. Energy intake was reduced at the greatest rate for treatments with *ad libitum* meals 4–5 hours after the treatment.

To evaluate the methods of measuring satiety, benefit was examined in terms of individual VAS questions. In the studies, the following VAS questions were used: satiety, hunger, desire to eat, appetite, fullness, and/or prospective consumption. Four studies calculated a composite appetite score from all VAS ratings collected. Table 7 shows the number of treatments using each method of measuring appetite that correspond to each level of benefit. Most of the satiety questions had similar rates of benefit. On the 2 extremes were appetite (low rate of benefit) and a composite appetite score calculated from all other satiety questions (relatively high rate of benefit). However, these 2 questions were used in a relatively low number of publications.

Table 5. Stratification of VAS Satiety and Food/Energy Intake Results by Fiber Dose

				Treatments With Specified Result**						
Outcome	Total Unavailable CHO (g)	Publications	Treatments*	75–100	50–74	25–49	1–24	0	0/N	N
VAS satiety	0.0–2.4	3	7	1	—	—	—	6	—	—
	2.5–4.9	14	21	1	3	1	3	13	—	—
	5.0–7.4	14	20	6	2	2	1	9	—	—
	7.5–9.9	11	15	1	1	3	1	9	—	—
	10.0–14.9	11	12	4	—	—	3	5	—	—
	15.0–19.9	6	9	1	—	—	1	5	2	—
	20.0–29.9	4	6	—	—	1	1	4	—	—
	30.0–39.9	5	8	1	—	1	1	5	—	—
	40.0–49.9	3	7	—	—	—	—	7	—	—
	50 +	2	2	1	—	1	—	—	—	—
	Total	73	107	16	6	9	11	63	2	0
Food/energy intake	0.0–2.4	2	6	—	—	—	—	6	—	—
	2.5–4.9	7	9	3	—	—	—	6	—	—
	5.0–7.4	7	11	2	—	—	—	9	—	—
	7.5–9.9	4	5	—	—	—	—	5	—	—
	10.0–14.9	5	5	1	—	—	—	3	—	1
	15.0–19.9	4	5	1	—	—	—	3	1	—
	20.0–29.9	4	6	1	—	—	—	5	—	—
	30.0–39.9	2	3	2	—	—	—	1	—	—
	40.0–49.9	3	5	2	—	—	—	3	—	—
	50.0 +	—	—	—	—	—	—	—	—	—
	Total	38	55	12	0	0	0	41	1	1

VAS = visual analogue scale; CHO = carbohydrate.

*Some publications tested more than one fiber type, fiber dose, or study design.

**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

Table 6. Distribution of Percentage Benefit Among VAS Satiety Collection End Times and *Ad Libitum* Meal Administration Times

				Treatments With Specified Result**					
Measurement	Time (h)	Publications	Treatments*	75–100	50–74	25–49	1–24	0	0/-
VAS end	0–0.9	1	10	0	0	0	0	10	0
	1–1.9	4	5	0	0	0	1	4	0
	2–2.9	9	17	1	1	1	1	13	0
	3–3.9	10	28	9	4	1	1	13	0
	4–4.9	5	10	0	3	1	2	3	1
	5–9.9	8	18	4	1	1	6	6	0
	10–14.9	3	8	2	0	0	0	5	1
	15 +	2	1	0	0	1	0	0	0
	Other†	6	10	0	0	1	0	9	0
Ad libitum meal	0–0.9	3	12	1	0	0	0	11	0
	1–1.9	2	4	0	0	0	0	3	1
	2–2.9	4	7	1	0	0	0	6	0
	3–3.9	8	13	4	0	0	0	9	0
	4–4.9	2	6	1	0	0	0	5	0
	5–9.9	1	1	0	0	0	0	1	0
	10–14.9	0	0	0	0	0	0	0	0
	15 +	1	1	0	0	0	0	1	0
	Other†	5	7	1	0	0	0	6	0

VAS = visual analogue scale.

*Some publications tested more than one fiber type, fiber dose, or study design

**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

†VAS end and *ad libitum* meal times could not be determined when the fiber treatment was given in multiple doses.

Table 7. Stratification of VAS Satiety and Food/Energy Intake Results by Method Used to Assess Appetite

Outcome	Measurement	Publications	Treatments*	Treatments With Specified Result for Individual Measurement** 75–100	50–74	25–49	1–24	0	0/N	N
VAS satiety	Satiety	25	72	10	9	2	2	49	—	—
	Hunger	29	60	8	2	2	1	45	2	—
	Desire to eat	18	44	6	1	1	—	36	—	—
	Appetite	3	10	1	—	—	—	9	—	—
	Fullness	29	61	12	2	3	2	42	—	—
	Prospective consumption	14	26	5	1	1	1	18	—	—
	Composite score	4	9	4	—	—	—	5	—	—
	Total	122	282	46	15	9	6	204	2	—
Food/energy intake	*Ad libitum* meal	22	50	9	—	—	—	40	1	—
	Remainder of day	11	16	6	—	—	—	9	—	1
	Total	33	66	15	0	0	0	49	1	1

VAS = visual analogue scale.

*Some publications tested more than one fiber type, fiber dose, or study design.

**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

Food and/or energy intake was measured by *ad libitum* meals in 50 treatments and by food records for the remainder of the test day in 16 treatments. Eleven treatments measured both *ad libitum* meals and remainder-of-day food records. As shown in Table 7, remainder-of-day food diaries resulted in a greater proportion of treatments with beneficial results than *ad libitum* meals.

Participant BMI

Treatments with participants in the average BMI ranges of <25.0, 25.0–29.9, and ≥30.0 were examined by BMI group, shown in Table 8. The proportion of treatments with 50% or greater benefit was higher when average BMI was at least 30.0 than when BMI was less than 25.0 and between 25.0 and 29.9. However, only 4 studies had an average BMI of ≥30, only 2 of which measured food intake.

DISCUSSION

Most fiber treatments did not have a significant effect on satiety and were even less likely to show a significant reduction of food intake. In comparison to other reviews on fiber, satiety, and food intake, which reported that at least half of the fiber studies were significant [9, 17, 18], this review found that only 39% of treatments were significant for satiety and 22% were significant for food intake. However, the previous reviews were not systematic reviews. One possible explanation for the greater effectiveness reported in the general reviews is the inclusion of long-term studies. Additionally, the method of assessing benefit in the general reviews is unknown.

There is evidence that β-glucan (from oats or barley), lupin kernel fiber, rye bran, whole grain rye, or a mixed high-fiber diet may decrease appetite more frequently than other fiber types.

Table 8. Stratification of VAS Satiety and Food/Energy Intake Results by Subject BMI

Outcome	Subject BMI	Publications	Treatments*	Treatments With Specified Result** 75–100	50–74	25–49	1–24	0	0/N	N
VAS satiety	<25.0	31	77	11	5	4	8	47	2	—
	25.0–29.9	5	15	2	—	4	1	8	—	—
	≥30.0	4	5	2	1	—	—	2	—	—
	No information	5	10	1	—	1	1	7	—	—
	Total	45	107	16	6	9	10	64	2	0
Food/energy intake	<25.0	16	34	7	—	—	—	24	1	1
	25.0–29.9	4	11	2	—	—	—	9	—	—
	≥30.0	2	3	2	—	—	—	2	—	—
	No information	4	7	1	—	—	—	6	—	—
	Total	26	55	12	0	0	0	41	1	1

VAS = Visual analogue scale; BMI = body mass index.

*Within publications, multiple treatments with differing duration, fiber dose, or other variables were tested.

**1–100: Percentage of satiety or food intake measurements that had significantly more benefit than controls. 0 = No effect; 0/N = mixed no/negative effect; N = negative effect.

Additionally, psyllium, whole grain barley, and wheat bran had a low to negative effect on VAS ratings, food intake, or both in the case of psyllium. Interestingly, these fiber sources represent a wide range of solubility, viscosity, and fermentability.

The effect of dose on satiety and food intake is still unclear. Consumption of total dietary fiber or total unavailable carbohydrate in the ranges 5.0–7.4 and 10.0–14.9 g demonstrated some benefit in VAS ratings, but this was not substantiated by decreased energy or food intake. Fibers in the range 30.0–49.9 g decreased food intake but had little effect on VAS ratings. Fiber type and fiber dose are interrelated. For example, many of the fiber doses between 30.0 and 49.9 g corresponded to resistant starch and Fiber One. However, the trends in fiber type are not entirely explained by fiber dose. In the fiber types showing the most benefit, the fiber dose was 13.7 g on average. In fibers showing the least benefit, the average dose was 26.2 g. Despite the hypothesis that the effective fiber dose may vary by fiber source, a greater dose did not enhance appetite control when examined within individual fiber types. However, there may be important differences in fiber composition that affect the effective dose, even among fibers from the same source.

Participant BMI, methods to assess appetite, and duration of the testing period may also influence satiety and food intake. However, measurements that appeared to be more or less likely to decrease appetite (BMI $\geq$ 30, VAS questions on appetite, composite appetite score) were studied in a low number of publications. The data suggest that ending VAS collection 3–15 hours after the fiber treatment may be the ideal time frame to see changes in satiety. However, fiber types might have effects on satiety at different times depending on their viscosity or fermentability, wherein the fibers might reduce the gastric emptying rate or produce their satiety-enhancing effect in the large intestine [9]. The greatest reduction in food intake was seen when *ad libitum* meals were administered 4–5 hours after fiber ingestion. However, very few studies administered *ad libitum* meals after this time.

When looking at specific fiber properties, there is some evidence that larger particle sizes might enhance satiety more than smaller particle sizes of the same fiber type. Increased time required for digestion of large particles and thus an extended but less severe glycemic response could contribute to this effect. Additionally, satiety signals that begin prior to ingestion (expected satiety) or during mastication may be stimulated more with large particle sizes. However, other fiber properties did not produce an effect in this review. Groups of fiber types known to be soluble, viscous, and/or fermentable did not consistently decrease appetite. Thus, this review did not support the hypothesis that soluble viscous fibers have greater appetite-suppressing effects than other fibers. In addition, neither the energy contribution of short-chain fatty acids nor the stimulation of gut peptides by short-chain fatty acids were confirmed as effective appetite-reducing mechanisms in this study.

VAS satiety ratings did not strongly agree with food/energy intake results, and a greater percentage of treatments enhanced satiety than reduced food intake. This is supported by previous studies, which have found that various dietary treatments affect satiety but do not influence food intake [11, 15]. It is hypothesized that learned behaviors and environmental cues, as well as satiety, guide eating habits [11]. The extent to which each of these components affects energy intake is unknown. There are limitations intrinsic to the measurement of satiety and food intake. VAS scales are subjective tools that are open to interpretation. Food records run the risk of underreporting or misreporting, whereas *ad libitum* meals may not represent typical eating behaviors. Preliminary work on satiety biomarkers has been done, but so far biomarkers are not sensitive or feasible enough to be used in clinical trials to reflect satiety sensations or predict food intake [68]. Furthermore, satiety and food intake may be sensitive to uncontrolled food and participant factors, such as sensory-specific satiety, environmental and social cues, palatability of the food, physical state of the food, stress level, sleeping habits, and perceived and expected fullness [69–72]. These factors may be more controlled in a single study than when comparing results between studies.

Limitations in design of the studies included in this review are unverified fiber doses and poorly controlled timing of *ad libitum* meal administration and VAS. Fiber types may vary considerably in ideal dose and time of maximum effectiveness, but many have not been sufficiently tested. Intact fiber in foods may have additional confounding factors. Whole grains, legumes, and vegetables contain bioactive components, protein, and other constituents that have an unknown effect on satiety [73, 74]. In many of the publications, the effect of bioactive components cannot be separated from the effect of the fibers.

This systematic review has limitations of its own. The results were summarized into tables without additional information, despite the wide variation in design of the studies reviewed. Each factor was analyzed independent of the others, even though there may be relationships between them. Additionally, percentage benefit, fiber dose, and treatment duration were given arbitrary cutoff points. Other researchers might have chosen these limits differently, producing slightly different results. Study designs varied greatly, with a wide range of sample sizes and study power among the trials.

A question that remains is, if fiber does not consistently enhance satiety and reduce food intake, what explains the relationship between fiber and weight management? One possibility is that VAS satiety and energy intake may not be sensitive enough to detect short-term changes in fiber intake the way they are being administered, or there may be too many confounding variables present in current satiety and food intake studies. If this is the case, greater environmental control, longer VAS collection periods, and greater sample sizes may improve the detection of changes due to fiber. Another possibility is that weeks or months are needed to detect changes, and therefore the next step is to review chronic studies in the same manner in which acute studies are reviewed in this article. Finally, it is possible that the relationship between fiber and body weight is not caused by appetite modulation. Other possible mechanisms for this reduction in body weight are increased satiation, which leads to the cessation of eating during a meal (and would still reduce food intake), or metabolic effects on fat breakdown and storage, potentially through insulin regulation [18, 75].

Thus, our systematic review of fiber and satiety and food intake yields a less positive relationship than earlier reviews of fiber and satiety [76]. A recent expert group evaluated the methodological challenges found in the evaluation of foods and food ingredients in appetite control [77]. Their report described the different designs used for assessing effects on satiation as opposed to satiety and provided an extensive discussion of the statistical procedures appropriate for handling data in this field of research. The objective of their paper was to give guidance on good practice in carrying out appetite research. Additional work is still needed on whether a change in hunger or satiety provides evidence for an effect on weight management.

CONCLUSION

This systematic review was conducted to determine the effect of fiber treatments on VAS satiety ratings and food or energy intake. Overall, 39% of treatments had a benefit on VAS satiety. For energy and food intake, only 22% of treatments significantly reduced intake. However, all fiber types did not affect appetite equally. β-Glucan, lupin kernel fiber, whole grain rye, rye bran, and a mixed fiber diet improved VAS ratings. These fiber types should be investigated further for possible use in obesity prevention. Other conclusions of this study are that very little agreement was found between appetite modulation and specific fiber properties, such as viscosity or fermentability. Furthermore, fiber treatments that had a benefit on satiety response often had little impact on energy intake and vice versa. In addition, inconsistent results were seen for fiber dose independent of fiber type, suggesting that fiber type may influence the optimal dose that is required to reduce appetite.

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