UNIVERSITY OF COPENHAGEN

A review of the characteristics of dietary fibers relevant to appetite and energy intake outcomes in human intervention trials

Poutanen, Kaisa S; Dussort, Pierre; Erkner, Alfrun; Fiszman, Susana; Karnik, Kavita; Kristensen, Mette Bredal; Marsaux, Cyril Fm; Miquel-Kergoat, Sophie; Pentikäinen, Saara P; Putz, Peter; Slavin, Joanne L; Steinert, Robert E; Mela, David J.

A review of the characteristics of dietary fibers relevant to appetite and energy intake outcomes in human intervention trials

Kaisa S Poutanen,[1] Pierre Dussort,[2] Alfrun Erkner,[3] Susana Fiszman,[4] Kavita Karnik,[5] Mette Kristensen,[6] Cyril FM Marsaux,[2] Sophie Miquel-Kergoat,[7] Saara P Pentikäinen,[1] Peter Putz,[2] Joanne L Slavin,[8] Robert E Steinert,[9] and David J Mela[10]

[1]VTT Technical Research Center of Finland, Espoo, Finland; [2]International Life Sciences Institute (ILSI) Europe a.i.s.b.l., Brussels, Belgium; [3]Nestec Ltd., Nestlé Research Center, Lausanne, Switzerland; [4]Institute of Agrochemistry and Food Technology, Paterna (Valencia), Spain; [5]Innovation and Commercial Development, Tate and Lyle, London, United Kingdom; [6]Department of Nutrition, Exercise, and Sports, University of Copenhagen, Copenhagen, Denmark; [7]Global Innovation Center–Wrigley (Mars Inc.), Chicago, IL; [8]Department of Food Science and Nutrition, University of Minnesota, St Paul, MN; [9]DSM Nutritional Products Ltd., R&D Human Nutrition and Health, Basel, Switzerland; and [10]Unilever R&D Vlaardingen, Vlaardingen, Netherlands

ABSTRACT

Background: Many intervention studies have tested the effect of dietary fibers (DFs) on appetite-related outcomes, with inconsistent results. However, DFs comprise a wide range of compounds with diverse properties, and the specific contribution of these to appetite control is not well characterized.

Objective: The influence of specific DF characteristics [i.e., viscosity, gel-forming capacity, fermentability, or molecular weight (MW)] on appetite-related outcomes was assessed in healthy humans.

Design: Controlled human intervention trials that tested the effects of well-characterized DFs on appetite ratings or energy intake were identified from a systematic search of literature. Studies were included only if they reported *1)* DF name and origin and *2)* data on viscosity, gelling properties, fermentability, or MW of the DF materials or DF-containing matrixes.

Results: A high proportion of the potentially relevant literature was excluded because of lack of adequate DF characterization. In total, 49 articles that met these criteria were identified, which reported 90 comparisons of various DFs in foods, beverages, or supplements in acute or sustained-exposure trials. In 51 of the 90 comparisons, the DF-containing material of interest was efficacious for ≥ 1 appetite-related outcome. Reported differences in material viscosity, MW, or fermentability did not clearly correspond to differences in efficacy, whereas gel-forming DF sources were consistently efficacious (but with very few comparisons).

Conclusions: The overall inconsistent relations of DF properties with respect to efficacy may reflect variation in measurement methodology, nature of the DF preparation and matrix, and study designs. Methods of DF characterization, incorporation, and study design are too inconsistent to allow generalized conclusions about the effects of DF properties on appetite and preclude the development of reliable, predictive, structure-function relations. Improved standards for characterization and reporting of DF sources and DF-containing materials are strongly recommended for future studies on the effects of DF on human physiology. This trial was registered at http://www.crd.york.ac.uk/PROSPERO as CRD42015015336. *Am J Clin Nutr* 2017;106:747–54.

INTRODUCTION

Various dietary recommendations and position reports urge individuals to consume adequate amounts of dietary fiber (DF) from a variety of sources (1). In observational studies, an increased intake of DF was associated with lower body weight (2, 3) or less weight gain (4). Almost 40 y ago, Van Itallie (5) noted the potentially beneficial role of DF in appetite control and recommended clinical investigations to assess the contribution of specific DFs in the prevention of obesity. DFs might affect appetite and energy intake (EI) directly through physical effects in

the gut [e.g. viscosity or gel formation (6)] or via effects of metabolites (short-chain fatty acids) resulting from fermentation of DF by gut bacteria (7). These DF functionalities, in turn, depend on the molecular properties of the DF and its interactions within the food and gastrointestinal milieu. Structural and functional DF properties with potential influences on appetite are shown in **Figure 1**. Although DF could affect EI directly, it is also possible that DF could influence appetite without a corresponding direct effect on EI. Reduced eating motivations per se may be beneficial in some situations (e.g., reducing dysphoria and improving compliance within the context of a controlled-energy weight-control regimen) (8).

In short- and long-term intervention studies, the reported effects of DFs on appetite and EI are variable (9, 10). This is not surprising, because DFs include a wide array of poly- and oligosaccharides with different composition and structure that occur intact in foods, or are extracted as mixtures or isolated as individual compounds of varying molecular weight (MW) (11, 12). Previous reviews classified and compared DFs by general class type and generic characteristics rather than by using the confirmed properties of DFs—actually measured and reported in studies—as the basis for analysis.

To date, to our knowledge, no comprehensive review has focused on elucidating which specific DF properties are most relevant for, and reliably predictive of, efficacy for reducing appetite and EI. Effects on these outcomes may be mediated by a number of mechanisms, potentially differing over acute and longer-term time frames (10, 13, 14). The way in which DF influences these mechanisms is highly dependent on its specific chemical and physical characteristics and the food matrix in which it is found. However, the specific source and nature of the DFs used in nutritional studies are often inadequately described, and their physical and chemical properties are very rarely tested and reported. This leads to uncertainty with regard to the exact nature of the DF tested, hinders attempts to explain variation in results in different experimental settings, and fails to advance the development of predictive structure-function relations for DF and health-related outcomes.

The underlying hypothesis of this work is that a specific source and dose of any particular DF can be seen as a vehicle for delivery for a set of physical and chemical conditions in the gastrointestinal tract that can affect appetite and EI. Our objective was therefore to assess the evidence for effects of specific DF characteristics on appetite and EI. To achieve this, we conducted a review in which a clear specification of the DF source used and its properties was among the inclusion criteria.

METHODS

This review was registered on the PROSPERO International Prospective Register of Systematic Reviews (registration CRD42015015336).

Data sources and searches

The full search strategy is described in **Supplemental Materials**. Although the systematic approach used here attempted to be comprehensive, the primary objective was to ensure that we identified a large, unbiased, representative sample of the literature. In brief, the MEDLINE (https://www.ncbi.nlm.nih.gov/pubmed/) and FSTA (https://foodinfo.ifis.org/fsta) databases were searched for studies published in English from 2005 to May 2016. Potentially relevant studies published before 2005 were identified from other current systematic and narrative reviews (9, 10, 15). Wanders et al. (10) used a search strategy and databases closely similar to those used here, whereas Clark and Slavin (9) used a somewhat more concise set of search terms.

Study selection

Intervention trials of any duration in apparently healthy adults (i.e., not patient populations) that examined the consumption of foods or diets where a treatment with a quantitative or qualitative difference in DF was compared with an appropriate control, with respect to appetite or EI, were included. For the purpose of this work, "appetite" is used as a generic term and refers to any self-reported feelings of hunger, satiety, fullness, desire to eat, etc., usually measured by using visual analog scales or comparable methods (16), and EI could be directly measured (e.g., weighed intake in the laboratory) or recorded by free-living subjects. The study selection was conducted in 2 screening phases. In the first phase of screening, the title and abstract of each article retrieved by the literature search were checked by pairs of scientists working independently (DJM, KK, RES, and SM-K). The article was taken to the second phase when either member of a pair judged it appropriate for further consideration.
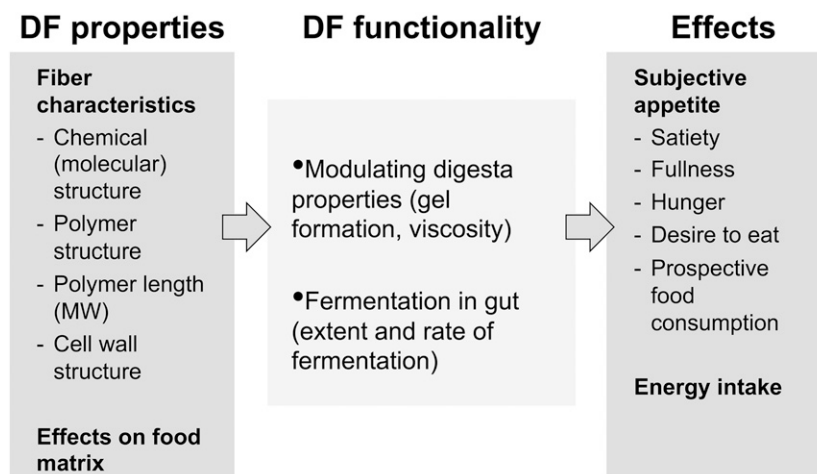

FIGURE 1 Structural and functional properties of DF and effects on eating behavior. DF, dietary fiber; MW, molecular weight.

In the second phase of screening, pairs of scientists (AE, DJM, JLS, KK, KSP, RES, SF, and SPP) individually evaluated the full text of each article identified in the first phase. A third reviewer resolved discrepancies in opinions with regard to inclusion of an article. Articles were excluded if the studies described were not original research publications of randomized controlled trials, if there was no appetite- or EI-related outcome, or if the DF source was not adequately described. At a minimum, adequate description required the DF name and origin plus ≥ 1 measure of the following properties: viscosity, gel formation, MW, or fermentability. Articles were included if they referred to another publication where this information was reported for the identical test material. Unlike the other properties considered, there is no established or direct quantitative physicochemical measure of "fermentability," and we therefore accepted a measurement of breath hydrogen as indication of the in vivo fermentability of DFs used in trials (17).

Data extraction and quality assessment

For the review approach, we followed the checklist and flowchart of the PRISMA (Preferred Reporting for Systematic Reviews and Meta-Analyses) guidelines (18). For each eligible study described in an article, data were extracted on the characterization of DF (source of DF, DF characterization method, food matrix, amount of DF, and confirmatory data for viscosity, gel formation, fermentation, or MW), along with the study design, nature and timing of outcome measures (e.g., appetite or EI), and an indication of the reporting of any significant effect (or not) on appetite or EI outcomes. Almost all of the studies reported appetite data as AUCs or similar time-averaged analysis, and this was used as the primary outcome when available. In the data synthesis, we treated a dose-response test of the same specific DF as a single comparison (test of a property), whereas tests of different DFs or DF preparations (e.g., different food vehicles) were considered separate comparisons, even if they were reported as part of the same experiment. This was done to prevent a loss of fidelity that would occur by combining treatments with completely different DF materials and properties. In addition, a "reduction" in appetite refers to a reduction in reported hunger or desire to eat, and/or an increase in satiety, fullness, etc., and the individual rating scales are only mentioned where relevant. Because the studies largely focused on the potential of DF to reduce appetite or EI, we characterized a significant reduction in either of these as a "beneficial" effect direction and a significant increase as a "detrimental" effect direction. Almost all of the acute studies used a similar "preload" design (16). However, given the more complex and variable nature of the sustained-exposure trials, 2 assessors (DJM and CFMM) independently undertook a concise assessment of potential risk-of-bias elements.

RESULTS

Eligible studies

The numbers of articles identified at each stage of the search and screening are shown in **Figure 2**. The primary reason for rejecting potentially eligible articles (149 of 322 articles in the second screening phase) was insufficient description of the DF.
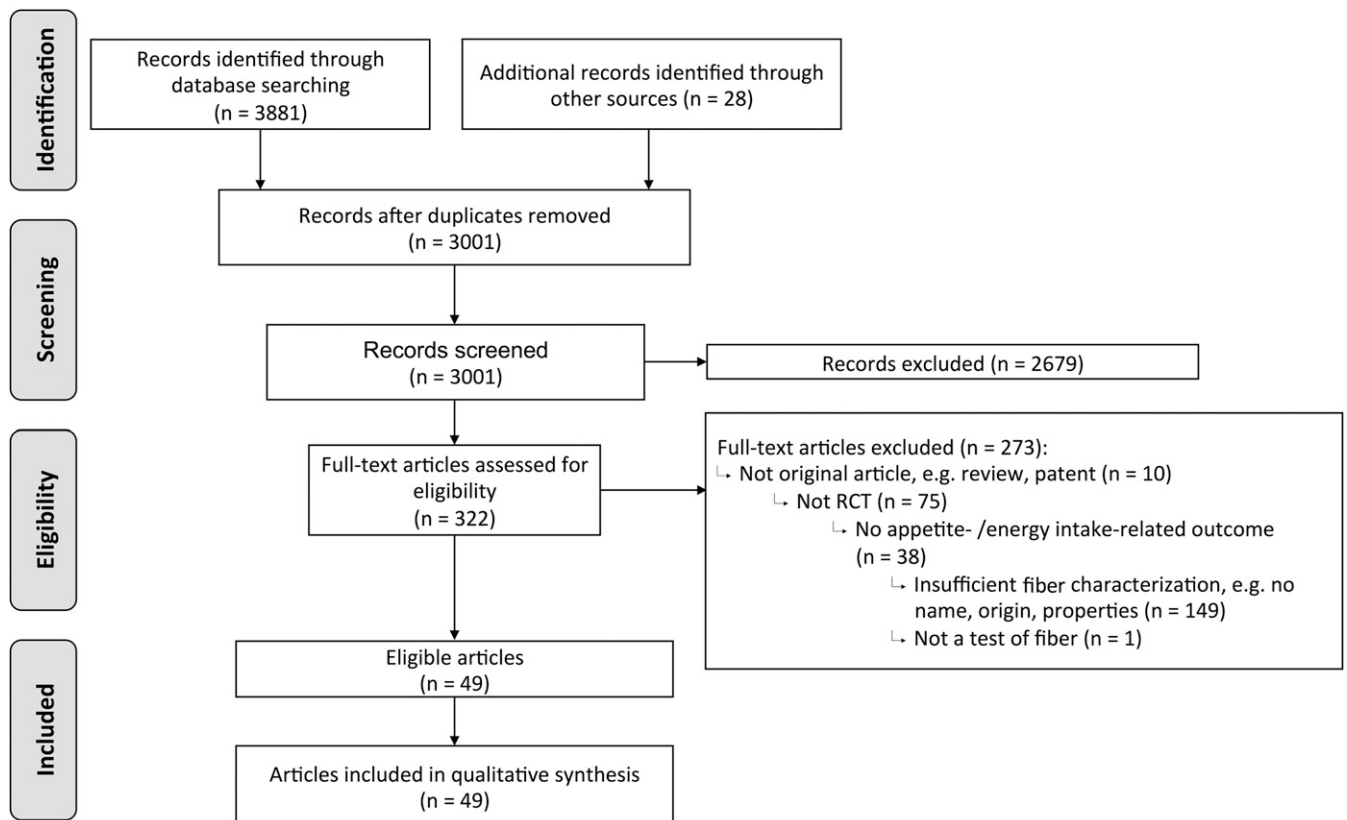

FIGURE 2 PRISMA flowchart of article selection. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT, randomized controlled trial.

The 49 articles that met our eligibility criteria included 90 DF comparisons in 40 acute (<1 d) and 12 sustained-exposure experiments, as summarized in **Supplemental Table 1**. Many of the included articles compared several different DF preparations, and some assessed >1 DF property. The majority of studies contained some form of an acute "preload" protocol, with or without a subsequent test meal, and therefore were not greatly differentiated in terms of basic design elements (16). However, the sustained trials were more complex and variable. A risk-of-bias assessment of these trials is reported in **Supplemental Table 2**. Key issues were frequent lack of power calculations (and few studies were powered for the outcomes relevant to this review), and missing or unclear intention-to-treat analyses.

Overall effects of DF on appetite and EI

Of the 90 DF comparisons studied, 51 resulted in ≥1 report of a significant beneficial effect on appetite, EI, or both (Supplemental Table 1). **Table 1** shows the aggregated proportions of DF comparisons per property that reported efficacious, beneficial (as well as any significant report of "detrimental") outcomes for appetite or EI in acute and sustained-exposure study designs.

Relation of different DF characteristics to appetite and EI outcomes

Viscosity

The largest proportion of studies (31 articles with 54 DF comparisons on appetite, EI, or both; Supplemental Table 1) dealt with DF characterized for viscosity, measured on DF ingredient or the test product, and either "as eaten" or under simulated gastric (e.g., low pH) conditions. The great majority of evidence was from acute designs (2–24 h), in which greater product or gastrointestinal viscosity derived from DF resulted in a reported

significant beneficial effect on appetite or EI measures in approximately one-half (27 of 49) or one-third (9 of 25) of the comparisons, respectively (Table 1). Only one comparison resulted in effects in the opposite direction (i.e., a significantly increased effect on appetite for a test product containing a higher-viscosity DF) (19). Although there were only a small number of comparisons that investigated sustained exposure to DF characterized for viscosity, these also suggested more consistently beneficial effects on appetite than EI (3 of 4 compared with 1 of 4 studies, respectively; Table 1).

The DF sources used to study the effects of viscosity varied greatly, including guar and locust bean gum, pectin, psyllium, alginate, and cereal β-glucan (Supplemental Table 1). Beverages were the most common food form used in the viscosity-related experiments (27 comparisons on DF in beverages and 6 testing combined beverage plus other products). The doses of DF reported as efficacious for appetite ranged from 0.25 g alginate (20) to 19.8 g alginate (21). For tests of beverages, the viscosity of the experimental DF products ranged from 33 to 56,500 millipascal-seconds (mPa·s) (Supplemental Table 1). The viscosity of the control beverage was either <1.0 mPa·s or in the range of ~30–60 mPa·s, with the exception of 1 study with a control with a viscosity as high as 2300 mPa·s (22). Significant appetite-decreasing effects were reported when DF treatments had product viscosities as low as 31.6 (23) or 55 mPa·s (24) against control beverages with viscosities of ≤1.5 mPa·s.

The methods applied for viscosity measurements were variable and were conducted either directly by using the liquid food matrix containing a variable amount of DF or under simulated gastric conditions at variable DF concentrations. The physical parameters applied in viscosity measurements also varied widely, with most using single-point shear rates typically in the range of 10–50 s^{-1}, a temperature of 20°C or 37°C, and a pH that was either not adjusted or adjusted to acidic (simulated gastric) conditions. The 10 articles that measured viscosity under gastric

TABLE 1
Proportion of comparisons of specific DF properties that showed a beneficial effect on EI or on ≥1 appetite rating, in acute or sustained exposure tests, out of all comparisons reported[1]

DF property and exposure	Number of DF comparisons generating a significant "beneficial" outcome for EI or for ≥1 appetite rating per total number of DF comparisons		Number of DF comparisons generating a significant "detrimental" outcome for EI or for ≥1 appetite rating
	Appetite	EI	
Viscosity			
Acute tests	27 of 49	9 of 25	1 (for appetite)
Sustained tests	3 of 4	1 of 4	0
Gelling			
Acute tests	4 of 4	1 of 2	0
Sustained tests	—	1 of 1	0
Fermentability			
Acute tests	8 of 26	2 of 11	1 (for appetite), 2 (for EI)
Sustained tests	4 of 4	0 of 3	0
MW			
Acute tests	14 of 19	3 of 10	0
Sustained tests	4 of 5	1 of 3	1 (for appetite)

[1] Reductions or increases in appetite or EI were characterized as a "beneficial" or "detrimental" effect, respectively. Note that the sum of comparisons for all 4 properties exceeds the 90 DF comparisons mentioned in text and reported in Supplemental Table 1 because some comparisons tested >1 DF property. DF, dietary fiber; EI, energy intake; MW, molecular weight.

conditions were mainly aimed at characterizing the properties of DF consumed in solid-food matrices. The variable ranges, matrices, and methods for viscosity precluded direct comparison of reported viscosity values and the identification of a specific or universally applicable product threshold viscosity for efficacy.

Gel formation

We found 5 articles (with 5 DF comparisons on appetite, EI, or both) that reported on DF characterized for gelling (Supplemental Table 1). All 4 acute comparisons with gelling DF reported a significant beneficial effect on appetite ratings (Table 1). Evidence of a beneficial effect on EI was reported in 1 of the 2 acute comparisons as well as in the only sustained study in which it was measured (Table 1). All of these studies used alginate with a source of calcium for their gel-forming properties, and often both viscosity and gel strength were measured under acidic, simulated gastric conditions. The dose of alginate used to achieve the effect in studies in which gel strength was reported was 1.5–19.8 g (Supplemental Table 1). A further article (20) reported that the addition of 0.25 g alginate to a control drink produced rapid gelling and had a significant effect on appetite, but actual gel strength was not measured. Given that the physical properties of alginate can change dramatically when exposed to acidic conditions, the articles generally concluded that apparent gastrointestinal rheology of the DF preparations was more important than their properties under preingestion product conditions.

Fermentability

On the basis of the reporting of breath hydrogen, we identified 14 articles with 30 DF comparisons testing the efficacy of DF fermentability on appetite, EI, or both (Supplemental Table 1). Results from acute studies were mixed for both appetite and EI outcomes, with the majority of tests (18 of 26 for appetite and 9 of 11 for EI) reporting no significant effect (Table 1). In contrast, all of the 4 sustained tests reported a significant beneficial effect on an appetite outcome, although none reported significant effects on EI. It should, however, be noted that in one study (25) increases in breath hydrogen observed in acute testing were not apparent after the sustained exposure and therefore the "fermentability" of the DF intervention when tested after sustained exposure was (by our criterion) not actually confirmed.

The doses used in the tests of fermentable DF ranged from 8–10 g (25–27) to 20–30 g (28–32) and ≤56 g DF (33). Most of the studies used inulin, oligofructose, and other oligosaccharides, but inherent DFs of rye and barley kernels were also tested (7, 30, 34).

MW

Data from 15 articles with 24 DF comparisons of effects of higher and lower MW DFs on appetite, EI, or both showed mixed results (Supplemental Table 1). Most of the acute (14 of 19) and sustained (4 of 5) tests reported significant beneficial changes in appetite ratings for a higher MW DF (Table 1). Only in 1 case did the inclusion of DF (an oat β-glucan with an MW of 80 kDa) have a detrimental effect on satiety (35). Significant beneficial effects of higher MW on EI were observed only in a small number of acute (3 of 10) and sustained (1 of 3) tests (Table 1). A higher MW as a property itself did not consistently reduce appetite, because some DF preparations with an MW of only 5 kDa (36, 37) reduced hunger, whereas a DF with an MW of 80 kDa decreased satiety (35). Furthermore, when the same DF preparation was used in high-MW and low-MW variants, the results were not consistent (18, 38). The control treatments were variable in these studies, and sometimes even when the DF MW was reported, this was not in scope for the study objective but rather the effect of other characteristics (e.g., food matrix properties) (39–42).

DISCUSSION

This review of well-characterized DF interventions confirms that although these are sometimes found to be efficacious for reducing appetite or EI, outcomes are not consistent or predictable from the DF properties considered. Of 90 DF comparisons, 51 indicated that DF characterized for viscosity, gelling, fermentability, MW, or a combination of these, had a beneficial effect on appetite ratings or EI. Gelling DF showed the most consistent beneficial effects on appetite, but these results were derived from only 5 comparisons. Conversely, fermentable DFs were least consistently efficacious. However, overall, the results varied considerably and there was no clear relation of reported properties with efficacy.

Although the results confirm that some DF interventions reduce appetite or EI, this effect was far from reliable, especially given the liberal criterion applied for the measured outcomes. In our analysis, we classified a treatment as efficacious on the basis of a single significant beneficial outcome (e.g., one appetite rating). Supplemental Table 1 shows that, in many cases, the overall results were actually more mixed, including examples in which most scales indicated a lack of significant efficacy (40, 43). Most acute studies are based on a standard basic design (16), but differences in a number of specific features within this design could introduce variability in the outcomes (44). The assessed risk of bias in sustained-exposure trials was generally low, but potential issues were apparent for power and (lack of) use of intention-to-treat analyses. In addition, the reliance on self-reported dietary intakes in most of the sustained-exposure studies could affect the quality and sensitivity of EI data.

Because a large proportion of original research that tested the effects of DF on appetite or EI outcomes did not adequately report the characterization of DF sources and properties, many of the studies included in other current reviews (9, 10, 15, 45) were not included here. Our inclusion criteria add a layer of scientific underpinning to the conclusions of earlier systematic reviews. Wanders et al. (10) reported somewhat more positive results for viscous fibers but also noted the poor consistency of evidence. Clark and Slavin (9) reported that a minority of DF interventions were efficacious and that "Neither fiber type nor fiber dose were related to satiety response or food intake."

Differences in the measurement of DF properties were also apparent: for example, viscosity measurements varied considerably (temperature, shear rate, hydration time, etc.). Properties were often reported only for the DF itself and not in the final food or beverage matrix. In addition, in some cases, properties were measured at ambient "product" conditions or under simulated gastric conditions, the latter probably being more relevant to postprandial physiologic effects. This is especially true in the case of alginates, which change in their properties from liquid to gel under gastric conditions (46).

We included fermentability as a DF characteristic of interest, alongside directly measurable physicochemical properties. This raises several issues. No other measures of confirming DF fermentability were identified in the selected studies other than breath hydrogen measurement as part of the clinical trial, 3–24 h after DF intake. In vitro measurements indicative of DF fermentability (47) could possibly be used in future studies to determine its relations with appetite. The physiologic time frame required for fermentation to occur may preclude the observation of significant behavioral effects within the typical 3- to 4-h acute experimental time frame (48, 49). This may also explain why fermentability had more consistently positive effects on appetite in sustained compared with acute exposures (28, 29, 34). It is also possible that some variation in efficacy within and between populations could be influenced by variation in the microflora or changes in this with sustained exposures.

There was some degree of variation in the study designs used, although the majority of acute studies applied a relatively established fixed "preload" design, followed by appetite ratings, with or without a subsequent ad libitum test meal (16). The follow-up time in these single-preload acute studies varied from 2 to 24 h, the latter affording opportunity to observe any so-called second meal effects later in the day (7, 30, 32, 34). Furthermore, studies varied in the nature of the form of delivery (food matrix or supplement) and doses and control treatments used. In many cases, the type and content of DF in the control product or background diet were unclear or not reported. DF exposure was often compared with no added DF (50–53), although sometimes with another type of DF (52, 54–56), with the same DF processed differently (23, 57, 58), or with different food formats (40, 43). The trials with sustained exposures were far more variable in terms of the frequency, duration, and nature of exposures (supplements or foods). Background diets pose another challenge, because they always contain other sources of DF and studies usually tested additions of DF above this.

As noted here and by others (15), most studies tested extracted or isolated DFs. However, experiments that used DFs inherently present as part of intact foods were also included (30, 34, 59). The DF quantities used in acute studies were most often in the range of 3–12 g, which represents 10–40% of the recommended daily intake of DF (1). Because the total DF intake is typically gathered from several meals and several DF sources, it may be challenging and unrealistic to serve the recommended daily amount in a single load. In some cases, servings of extracted or isolated DFs at lower amounts (generally <3–5 g) produced significant beneficial effects on appetite; however, doses as high as 56.7 g were also used (33).

The major strength of the current review was the selection of studies on the basis of a clear description of the DF source and confirmation (i.e., measurement) of properties hypothesized to influence appetite or EI. This places clear emphasis on generating predictable structure-function relations of DFs rather than the empirical testing of particular DF mixes. This understanding is warranted to advance knowledge on the role of DFs in nutrition, and for improved specification and preclinical testing of food components that potentially have physiologic functions relevant for specific health-related outcomes.

On the other hand, the criteria we applied excluded a large number of otherwise well-conducted clinical trials because of a lack of characterization of the DF used. Often, the description of DF in nutrition research is still limited to a generic type or source name ("flax fiber," "oat bran," "alginate," "guar gum," etc.), without apparent realization that these encompass a very wide range of materials with different polymer structures, MWs, and complexity, and correspondingly varying effects in the gastrointestinal tract. Such limited descriptions leave uncertainty about what was actually tested and make direct replication and generalization of results virtually impossible. Even where the DF itself is specified, the physicochemical properties are rarely confirmed in the test food, which leaves little basis for predicting (e.g., from benchtop tests) the likely efficacy of the same DF in other formats.

A further limitation of our approach is that DFs are classified only according to the physicochemical characteristics tested, without any consideration of whether the differences in DF characteristics were sufficiently large or appropriate to test for an eating-inhibitory effect. For example, the absence of beneficial effects of an oat β-glucan with an MW of 80 kDa (35) may not be very surprising when the average MW ($\sim$2,000,000 Da) and associated viscosity of natural oat β-glucans are much higher (60). On the other hand, a point shown by this review is that we lack the data for specific properties (measured in specific ways) to make these judgments a priori.

In conclusion, the results here show inconsistencies in the effects of DF properties on appetite and EI and the need for improved standardization for the specification, characterization, and reporting of DF used in nutrition intervention studies. At the very least, we would recommend that the exact materials are described in a way that allows sourcing and replication, along with the quantities (background diet and intervention) and the matrix and manner of incorporation, accompanied by explicit reference to physicochemical properties measured in a way that is standardized and relevant to the putative physiologic effects. We note that guidelines for the use and reporting of other complex materials, such as botanical supplements, have been in place (and adopted by this Journal) for many years (61). Similar guidance applied to DF is essential to develop mechanistic knowledge and more reliable prediction of the effects of specific DFs in nutrition.

REFERENCES

1. Dahl WJ, Stewart ML. Position of the Academy of Nutrition and Dietetics: health implications of dietary fiber. J Acad Nutr Diet 2015;115:1861–70.

2. Liu S, Willett WC, Manson JE, Hu FB, Rosner B, Colditz G. Relation between change in intakes of dietary fiber and grain products and changes in weight and development of obesity among middle-aged women. Am J Clin Nutr 2003;78:920–7.

3. Du H, Van Der A DL, Boshuizen HC, Forouhi NG, Wareham NJ, Halkjær J, Tjønneland A, Overvad K, Jakobsen MU, Boeing H, et al. Dietary fiber and subsequent changes in body weight and waist circumference in European men and women. Am J Clin Nutr 2010;91: 329–36.

4. Ye EQ, Chacko S, Chou E, Kugizaki M, Liu S. Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. J Nutr 2012;142:1304–13.

5. Van Itallie TB. Dietary fiber and obesity. Am J Clin Nutr 1978;31 (Suppl):S43–52.

6. Papathanasopoulos A, Camilleri M. Dietary fiber supplements: effects in obesity and metabolic syndrome and relationship to gastrointestinal functions. Gastroenterology 2010;138:65–72.e1-2.

7. Nilsson AC, Ostman EM, Holst JJ, Bjorck IM. Including indigestible carbohydrates in the evening meal of healthy subjects improves glucose tolerance, lowers inflammatory markers, and increases satiety after a subsequent standardized breakfast. J Nutr 2008;138:732–9.

8. Hetherington MM, Cunningham K, Dye L, Gibson EL, Gregersen NT, Halford JCG, Lawton CL, Lluch A, Mela DJ, Van Trijp HCM. Potential benefits of satiety to the consumer: scientific considerations. Nutr Res Rev 2013;26:22–38.

9. Clark MJ, Slavin JL. The effect of fiber on satiety and food intake: a systematic review. J Am Coll Nutr 2013;32:200–11.

10. Wanders AJ, van den Borne JJGC, de Graaf C, Hulshof T, Jonathan MC, Kristensen M, Mars M, Schols HA, Feskens EJM. Effects of dietary fibre on subjective appetite, energy intake and body weight: a systematic review of randomized controlled trials. Obes Rev 2011;12:724–39.

11. Lupton JR, Betteridge VA, Pijls LTJ. Codex final definition of dietary fibre: issues of implementation. Qual Assur Saf Crops Foods 2009;1: 206–12.

12. Raninen K, Lappi J, Mykkänen H, Poutanen K. Dietary fiber type reflects physiological functionality: comparison of grain fiber, inulin, and polydextrose. Nutr Rev 2011;69:9–21.

13. McRorie JW. Evidence-based approach to fiber supplements and clinically meaningful health benefits, part 2: what to look for and how to recommend an effective fiber therapy. Nutr Today 2015;50:90–7.

14. Fiszman S, Varela P. The role of gums in satiety/satiation: a review. Food Hydrocoll 2013;32:147–54.

15. Kristensen M, Jensen MG. Dietary fibres in the regulation of appetite and food intake: importance of viscosity. Appetite 2011;56:65–70.

16. Blundell J, De Graaf C, Hulshof T, Jebb S, Livingstone B, Lluch A, Mela D, Salah S, Schuring E, Van Der Knaap H, et al. Appetite control: methodological aspects of the evaluation of foods. Obes Rev 2010;11: 251–70.

17. McBurney MI, Thompson LU. Fermentative characteristics of cereal brans and vegetable fibers. Nutr Cancer 1990;13:271–80.

18. Moher D, Liberati A, Tetzlaff J, Altman DG, Grp P. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement (reprinted from Annals of Internal Medicine). Phys Ther 2009;89:873–80.

19. Juvonen KR, Purhonen A-K, Salmenkallio-Marttila M, Lahteenmaki L, Laaksonen DE, Herzig K-H, Uusitupa MIJ, Poutanen KS, Karhunen LJ. Viscosity of oat bran-enriched beverages influences gastrointestinal hormonal responses in healthy humans. J Nutr 2009; 139:461–6.

20. Solah VA, Kerr DA, Adikara CD, Meng X, Binns CW, Zhu K, Devine A, Prince RL. Differences in satiety effects of alginate- and whey protein-based foods. Appetite 2010;54:485–91.

21. Jensen MG, Knudsen JC, Viereck N, Kristensen M, Astrup A. Functionality of alginate based supplements for application in human appetite regulation. Food Chem 2012;132:823–9.

22. Rigaud D, Paycha F, Meulemans A, Merrouche M, Mignon M. Effect of psyllium on gastric emptying, hunger feeling and food intake in normal volunteers: a double blind study. Eur J Clin Nutr 1998;52: 239–45.

23. Lyly M, Ohls N, Lähteenmäki L, Salmenkallio-Marttila M, Liukkonen KH, Karhunen L, Poutanen K. The effect of fibre amount, energy level and viscosity of beverages containing oat fibre supplement on perceived satiety. Food Nutr Res 2010;54:1–8.

24. Barone Lumaga R, Azzali D, Fogliano V, Scalfi L, Vitaglione P. Sugar and dietary fibre composition influence, by different hormonal response, the satiating capacity of a fruit-based and a β-glucan-enriched beverage. Food Funct 2012;3:67–75.

25. Wanders AJ, Mars M, Borgonjen-van den Berg KJ, de Graaf C, Feskens EJM. Satiety and energy intake after single and repeated exposure to gel-forming dietary fiber: post-ingestive effects. Int J Obes (Lond) 2014;38:794–800.

26. Hess JR, Birkett AM, Thomas W, Slavin JL. Effects of short-chain fructooligosaccharides on satiety responses in healthy men and women. Appetite 2011;56:128–34.

27. Morris C, Lynn A, Neveux C, Hall AC, Morris GA. Impact of bread making on fructan chain integrity and effect of fructan enriched breads on breath hydrogen, satiety, energy intake, PYY and ghrelin. Food Funct 2015;6:2561–7.

28. Cani PD, Lecourt E, Dewulf EM, Sohet FM, Pachikian BD, Naslain D, De Backer F, Neyrinck AM, Delzenne NM. Gut microbiota fermentation of prebiotics increases satietogenic and incretin gut peptide production with consequences for appetite sensation and glucose response after a meal. Am J Clin Nutr 2009;90:1236–43.

29. Daud NM, Ismail NA, Thomas EL, Fitzpatrick JA, Bell JD, Swann JR, Costabile A, Childs CE, Pedersen C, Goldstone AP, et al. The impact of oligofructose on stimulation of gut hormones, appetite regulation and adiposity. Obesity (Silver Spring) 2014;22:1430–8.

30. Johansson EV, Nilsson AC, Östman EM, Björck IME. Effects of indigestible carbohydrates in barley on glucose metabolism, appetite and voluntary food intake over 16 h in healthy adults. Nutr J 2013;12:46.

31. Johansson Boll EV, Ekström LM, Courtin CM, Delcour JA, Nilsson AC, Björck IM, Östman EM. Effects of wheat bran extract rich in arabinoxylan oligosaccharides and resistant starch on overnight glucose tolerance and markers of gut fermentation in healthy young adults. Eur J Nutr 2015;55:1661–70.

32. Karalus M, Clark M, Greaves KA, Thomas W, Vickers Z, Kuyama M, Slavin J. Fermentable fibers do not affect satiety or food intake by women who do not practice restrained eating. J Acad Nutr Diet 2012; 112:1356–62.

33. Konings E, Schoffelen PF, Stegen J, Blaak EE. Effect of polydextrose and soluble maize fibre on energy metabolism, metabolic profile and appetite control in overweight men and women. Br J Nutr 2014;111:111–21.

34. Sandberg JC, Björck IME, Nilsson AC. Rye-based evening meals favorably affected glucose regulation and appetite variables at the following breakfast; a randomized controlled study in healthy subjects. PLoS One 2016;11:e0151985.

35. Biörklund M, Holm J, Önning G. Serum lipids and postprandial glucose and insulin levels in hyperlipidemic subjects after consumption of an oat β-glucan-containing ready meal. Ann Nutr Metab 2008;52:83–90.

36. Guérin-Deremaux L, Li S, Pochat M, Wils D, Mubasher M, Reifer C, Miller LE. Effects of NUTRIOSE(R) dietary fiber supplementation on body weight, body composition, energy intake, and hunger in overweight men. Int J Food Sci Nutr 2011;62:628–35.

37. Guérin-Deremaux L, Pochat M, Reifer C, Wils D, Cho S, Miller LE. The soluble fiber NUTRIOSE induces a dose-dependent beneficial impact on satiety over time in humans. Nutr Res 2011; 31:665–72.

38. Smith KN, Queenan KM, Thomas W, Fulcher RG, Slavin JL. Physiological effects of concentrated barley beta-glucan in mildly hypercholesterolemic adults. J Am Coll Nutr 2008;27:434–40.

39. Isaksson H, Rakha A, Andersson R, Fredriksson H, Olsson J, Aman P. Rye kernel breakfast increases satiety in the afternoon—an effect of food structure. Nutr J 2011;10:31.

40. Rebello CJ, Chu Y, Johnson WD, Martin CK, Han H, Bordenave N, Shi Y, Shea MO, Greenway FL. The role of meal viscosity and oat β-glucan characteristics in human appetite control: a randomized crossover trial. Nutr J 2014;13:49–58.

41. Rebello CJ, Johnson WD, Martin CK, Xie W, O'Shea M, Kurilich A, Bordenave N, Andler S, van Klinken BJW, Chu Y-F, et al. Acute effect of oatmeal on subjective measures of appetite and satiety compared to a ready-to-eat breakfast cereal: a randomized crossover trial. J Am Coll Nutr 2013;32:272–9.

42. Rebello CJ, Johnson WD, Martin CK, Han H, Chu Y-F, Bordenave N, Klinken BJWV, O'Shea M, Greenway FL. Instant oatmeal increases satiety and reduces energy intake compared to a ready-to-eat oat-based breakfast cereal: a randomized crossover trial. J Am Coll Nutr 2016;35: 41–9.

43. Pentikäinen S, Karhunen L, Flander L, Katina K, Meynier A, Aymard P, Vinoy S, Poutanen K. Enrichment of biscuits and juice with oat β-glucan enhances postprandial satiety. Appetite 2014;75:150–6.

44. Zaremba SMM, Drummond S, Steinert RE. The need to standardize ad libitum eating protocols in dietary fibre appetite research. Eur J Clin Nutr 2017;71:570–2.

45. El Khoury D, Goff HD, Anderson GH. The role of alginates in regulation of food intake and glycemia: a gastroenterological perspective. Crit Rev Food Sci Nutr 2015;55:1406–24.

46. Ström A, Boers HM, Koppert R, Melnikov SM, Wiseman S, Peters HPF. Physico-chemical properties of hydrocolloids determine their appetite effects. In: Phillips GO, editor. Gums and stabilisers for the food industry. London: Royal Society of Chemistry; 2009. p. 341–55.

47. Barry JL, Hoebler C, Macfarlane T, Macfarlane S, Mathers JC, Reed KA, Mortensen B, Nordgaard I, Rowland IR, Rumney C. Estimation of the fermentability of dietary fibre in vitro: a European interlaboratory study. Br J Nutr 1995;74:303–22.

48. Hanson CF, Winterfeldt EA. Dietary fiber effects on passage rate and breath hydrogen. Am J Clin Nutr 1985;42:44–8.

49. Royall D, Wolever TM. Relationship between foods of varying fermentability and colonically derived blood acetate. Nutr Res 1991;11:1137–46.

50. Ibrügger S, Kristensen M, Mikkelsen MS, Astrup A. Flaxseed dietary fiber supplements for suppression of appetite and food intake. Appetite 2012;58:490–5.

51. El Khoury D, Goff H, Berengut S, Kubant R, Anderson G. Effect of sodium alginate addition to chocolate milk on glycemia, insulin, appetite and food intake in healthy adult men. Eur J Clin Nutr 2014;68:613–8.

52. Lyly M, Liukkonen KH, Salmenkallio-Marttila M, Karhunen L, Poutanen K, Lähteenmäki L. Fibre in beverages can enhance perceived satiety. Eur J Nutr 2009;48:251–8.

53. Mikušová L, Ciesarová Z, Hromádková Z, Valachovišová M, Penesová A, Kajaba I, Holubková A, Krajčíová Ľ, Mislovišová D, Bobrík M, et al. Novel cereal fibre drink as a tool for civilisation disease prevention. Qual Assur Saf Crops Foods 2014;6:357–66.

54. Paquet É, Bédard A, Lemieux S, Turgeon SL. Effects of apple juice-based beverages enriched with dietary fibres and xanthan gum on the glycemic response and appetite sensations in healthy men. Bioact Carbohydrates Diet Fibre 2014;4:39–47.

55. Peters HPF, Boers HM, Haddeman E, Melnikov SM, Qvyjt F. No effect of added β-glucan or of fructooligosaccharide on appetite or energy intake. Am J Clin Nutr 2009;89:58–63.

56. Wanders AJ, Jonathan MC, van den Borne JJGC, Mars M, Schols HA, Feskens EJM, de Graaf C. The effects of bulking, viscous and gel-forming dietary fibres on satiation. Br J Nutr 2013;109:1330–7.

57. Logan K, Wright AJ, Goff HD. Correlating the structure and in vitro digestion viscosities of different pectin fibers to in vivo human satiety. Food Funct 2015;6:63–71.

58. Marciani L, Gowland PA, Spiller RC, Manoj P, Moore RJ, Young P, Fillery-Travis AJ. Effect of meal viscosity and nutrients on satiety, intragastric dilution, and emptying assessed by MRI. Am J Physiol Gastrointest Liver Physiol 2001;280:G1227–33.

59. Nilsson A, Johansson E, Ekstrom L, Bjorck I. Effects of a brown beans evening meal on metabolic risk markers and appetite regulating hormones at a subsequent standardized breakfast: a randomized cross-over study. PLoS One 2013;8:e59985.

60. Regand A, Chowdhury Z, Tosh SM, Wolever TMS, Wood P. The molecular weight, solubility and viscosity of oat beta-glucan affect human glycemic response by modifying starch digestibility. Food Chem 2011;129:297–304.

61. Swanson CA. Suggested guidelines for articles about botanical dietary supplements. Am J Clin Nutr 2002;75:8–10.