Original Article

Dietary fibre content and nutrient claims relative to the faecal bulking efficacy of breakfast cereals

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The correspondence between the dietary fibre contents of 28 breakfast cereals and their faecal bulking efficacies was measured and used to assess criterion values controlling nutrient claims for dietary fibre. A valid, standardised rat assay was used to measure faecal bulking efficacy as the content of wheat bran equivalents for faecal bulk (WBE_{fb}) in the cereals. Regression analysis of WBE_{fb} content against dietary fibre content allowed the adequacy of criterion fibre values for claims of 'source of fibre,' 'high in fibre' and 'very high in fibre' to be assessed relative to a daily reference requirement of 63 WBE_{fb}, based on human data. Faecal bulking by breakfast cereals was much lower than implied by the dietary fibre claims associated with them. Many more were claimed to be 'high' or 'very high' in dietary fibre ($n = 13$) than were 'high' or 'very high' in faecal bulking efficacy ($n = 4$). Conversely, dietary fibre requirements per serving predicted from WBE_{fb} requirements, as necessary to maintain adequate faecal bulk in the current Australian diet, were much higher (4.4 g) than the criterion fibre content (1.5 g) for the most modest claim, 'source of fibre'. After removing four high-bran cereals (>15% dietary fibre) from the analysis, a modest correlation of $r = 0.62$ between dietary fibre content and faecal bulk was obtained. It is concluded that, with respect to breakfast cereals, fibre values specified for nutrient claims are too low, dietary fibre content is not a reliable guide to faecal bulking efficacy and direct measures of faecal bulking capacity would be more useful than dietary fibre content in describing faecal bulking efficacy for evidence-based food choice.

Key words: breakfast cereals, dietary fibre, faecal bulk, wheat bran equivalents.

Introduction

The need for valid data sets to enable foods to be chosen for the functional effects that link them to health end points has been of recent concern.[1] There are few evidence-based measures of relative efficacy that allow effective foods to be selected from the enormous array of competing products now available.[2]

Constipation is an example of a widespread disorder against which a functional food component, dietary fibre, is commonly assumed to confer protection. Many consumers see dietary fibre as synonymous with laxation,[3,4] and they expect dietary fibre values in nutrition information panels, and associated nutrient claims, to be valid guides to the relative faecal bulking efficacies of foods. Such an expectation is consistent with the original concept of dietary fibre as 'roughage'.[5]

However, the dietary fibre content of a food on its own can no longer be assumed to indicate a food's faecal bulking capacity, because the definition of dietary fibre admits many food components with little faecal bulking potential and is linked to a number of health end points that are unrelated to the large bowel.[6] Dietary fibre, as analysed for food labels, cannot, by definition, be assumed to predict type or size of any specific physiological effect, such as faecal bulking. Also, dietary fibre is but one contributor to faecal bulk amongst a complete range of undigested and unfermented food residues, which may be variously transformed in the colon.[7] In addition, a large quantity of bacteria of colonic origin, and water retained by the whole faecal mass, are major contributors to faecal bulk.[8]

Breakfast cereals are commonly believed to be capable of providing a substantial proportion of the daily requirement for faecal bulk through their dietary fibre component, and much is made of their presumed role in maintaining 'inner health'. The relative ability of a wide range of breakfast cereals to increase faecal bulk has recently been measured with a standardised *in vivo* test that allows comparison of a large number of foods under tightly controlled conditions.[9] With wheat bran as a reference material, and using an animal model developed for the purpose,[10] a faecal bulking index (FBI) was calculated. FBI is the increment in hydrated faecal weight due to a food as a percentage of the increase due to an equal weight of wheat bran, and it was used to derive wheat bran equivalents for faecal bulk (WBE_{fb}).[11]

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Wheat bran equivalents for faecal bulk is the amount of wheat bran equivalent to a weight of food in its faecal bulking action. A useful property of WBE_{fb} is that it may be related to any food quantity, such as a serving, so that a direct comparison can be made of faecal bulking efficacy and nutrition claims for dietary fibre, which are based on dietary fibre content per 100 g or per serving of food. So, if the relationship between dietary fibre content and faecal bulking is established for breakfast cereals, and an evidence-based daily reference value for faecal bulk can be derived, dietary fibre levels that are appropriate for nutrition claims may be identified within the context of food and nutrition guidelines.

This paper reports an examination of the relationship of dietary fibre content and related nutrient claims to the faecal bulking efficacy of breakfast cereals. The WBE_{fb} contents of 28 Australasian breakfast cereals are determined and used to assess their ability to contribute to a theoretical daily reference value for faecal bulk (DRV_{fb}). The results thus allowed the validity of nutrient claims for dietary fibre in the breakfast cereals to be tested with respect to faecal bulking efficacy.

Materials and methods

Samples

The breakfast cereals subjected to faecal bulking assays were sampled to cover much of the range of cereal types available in New Zealand supermarkets, and avoided duplicating the same types of sample that differed only in flavour (such as chocolate *vs* plain rice bubbles) or in manufacturer (as in numerous brands of rolled oats and muesli). The breakfast cereals, obtained from local supermarkets, were: All Bran® (Kellogg's), Berry Berry Nice (Hubbard's), Bran Flakes™ (Kellogg's), Chex® (Kellogg's), Cornflakes™ (Kellogg's), Creamoata (Fleming's), Fruitful Porridge (Hubbard's), Fruity Bix® (Sanitarium), Just Right® (Kellogg's), Kornies (Sanitarium), Miniwheats™ (Kellogg's), Muesli (Unsweetened; Sanitarium), Multiflakes (Lowan), Nut Feast (Uncle Tobys), Nutrigrain® (Kellogg's), Oat Bran (Fleming's), Puffed rice (Sanitarium Ricies), Puffed Wheat (Sanitarium), Rolled Oats (Fleming's), Rolled Oats (Pam's), San Bran (Sanitarium), Special K® (Kellogg's), Sports Plus (Uncle Tobys), Sultana bran (Kellogg's), Sustain® (Kellogg's), Vita Brits® (Grain Products), Vita Crunch (Fleming's), Wheat Biscuits (Kellogg's). Wheat bran was obtained from a local flour mill (Champion Mills, Palmerston North, New Zealand). All breakfast cereals and the wheat bran reference were milled to pass through a 2-mm sieve.

Dietary fibre content

Dietary fibre values were obtained from the nutrient information panels on the cereal packets or, where not available, from the New Zealand Food Composition Database.[12] Reliance on such fibre data is justified in the context of this paper, which investigates the relationship between effects of cereal products and dietary fibre values provided for consumers to use as a basis for nutrition claims.

Diets and feeding

The trials used mature rats (400 ± 50 g) that had been pre-adapted to mixed dietary fibre since weaning. The composition of the diets and the feeding protocol for the trials have been detailed elsewhere.[9] Briefly, during the assay period rats were fed a nutritionally complete baseline diet containing 50 g sucrose/100 g diet, a reference diet in which 12.5 g of the sucrose in the baseline diet was replaced by wheat bran, and test diets in which the 50 g sucrose was completely replaced by the breakfast cereal.

Measurement of FBI

Faeces were collected over a four-day balance period, dried, weighed, and a subsample was rehydrated to saturation and reweighed.

Calculations

Faecal bulking indices. Faecal bulking indices were calculated as the increase in rehydrated faecal weight induced by a food compared with baseline, as a percentage of the increase due to consumption of an equal weight of wheat bran.

FBI = Increase over baseline in mass of rehydrated faeces per g of test food consumed × 100/Increase over baseline in mass of rehydrated faeces per g of reference food consumed (1)

The following formula was used to calculate FBI:

$$FBI = (T\text{-}B/R\text{-}B) \times (Pr/Pf) \times 100 \quad (2)$$

Where:

FBI = faecal bulking index

T = mass of rehydrated faeces/100 g feed intake for test diet

B = mass of rehydrated faeces/100 g feed intake for baseline diet

R = mass of rehydrated faeces/100 g feed intake for reference diet

Pr = proportion of reference material in reference diet

Pf = proportion of test food in test diet

Wheat bran equivalents for faecal bulk. Wheat bran equivalents for faecal bulk per gram of breakfast cereal were taken as FBI/100 (FBI of wheat bran reference = 100). The WBE_{fb} content per serving was then calculated using serving sizes given in the nutrition information panels on the breakfast cereal packets. From WBE_{fb} content per serving, a percentage contribution to a theoretical DRV_{fb} per serving was calculated.

Daily reference value for faecal bulk. A daily reference value for faecal bulk was determined as follows: 1 g of wheat dietary fibre increases faecal weight by 5.11 ± 1.34 g in humans (mean of 27 studies).[13] A stool weight of at least 150 g/day is associated with reduced colorectal cancer in Australians.[14] The weight of wheat dietary fibre providing 150 g stool is therefore 150/5.11 = 29.4 g. As wheat bran contains 0.435 g dietary fibre/g,[12] 29.4/0.435 = 67.6 g of it gives 150 g faecal bulk. One common standard measure, a standard 250 mL cup of wheat bran, weighs 63 g and supplies $63 \times 0.435 = 27.4$ g dietary fibre, which is almost exactly the

mean (27.5 g) of the recommended daily intakes of fibre for men (30 g) and women (25 g).[15] The DRV_{fb} was therefore set conservatively at 63 WBE_{fb}, based on the conjunction of the above lines of evidence. It is not a recommended intake of wheat bran, but an equivalent (in its effect) to accumulated bulk from all sources per day, for an average adult.

Classification of breakfast cereals

Classification by nutrient claims made and eligibility to claim. Categories were based on nutrient claims for dietary fibre, no claim, source of fibre, high in fibre, and very high in fibre, for which the intervals were, <1.5, 1.5–3, 3–6 and >6 g dietary fibre per serving, respectively, as specified in the Food Standards Australia New Zealand (FSANZ) food standards.[16]

Classified by ability to contribute faecal bulk in the CSIRO12345+ plan for adults. The CSIRO12345+ plan modified for adults includes nine cereal + four vegetable + three fruit = 16 servings per day of plant-based foods that contribute dietary fibre.[17] WBE_{fb} contributions per serving were defined as low if insufficient to provide the DRV_{fb} in the recommended number of servings of fibre sources. Based on DRV_{fb} (63 WBE_{fb}/day), any source providing less than $63/16 = 3.94 \approx 4$ WBE_{fb} per serving was therefore defined as low in fibre. The intervals were therefore set at: low, <4; medium, 4–8; high, 8–12; and very high, >12 WBE_{fb} per serving for the CSIRO12345+ diet.

The WBE_{fb} contribution per serving of foods in the four categories would be <1, 1–2, 2–3 and >3 times the level adequate to maintain faecal bulk. The high category included breakfast cereals that would contribute 19% or more of the DRV_{fb} in one serving, while the low category would contain samples contributing less than 6.2% in a serving.

Classification based on the range of WBE_{fb} contents measured. The faecal bulking efficacies measured extended from –0.52 (Cornflakes) to 36.78 (San Bran), or approximately 0–40 WBE_{fb} per serving. Equal intervals were therefore set at: low, <10; medium, 10–20; high, 20–30; and very high, >30 WBE_{fb} per serving. The 'very high' category (>30 WBE_{fb} per serving) therefore corresponded to almost half of the DRV_{63} (63 WBE_{fb}) in a single serving, which is consistent with the amount (15 g) of fibre in one serving of San Bran (45 g) being 50% of the recommended dietary intake (RDI) (30 g) for dietary fibre.

WBE_{fb} required per serving of dietary fibre sources to provide the DRV_{fb} in recommended and actual diets

The WBE_{fb} required per serving to achieve the DRV_{fb} in a diet is DRV_{fb} divided by the number of servings of fibre sources (cereals, fruit, vegetables) in the diet. WBE_{fb} requirements per serving of dietary fibre sources were calculated for several diets: CSIRO12345+ food and nutrition plan, 5.25;[17] CSIRO12345+ plan modified for adults, 3.93;[17] United States Department of Agriculture (USDA) food pyramid, 4.1; American actual intakes (NDP Group), 14.3;[18] and Australian actual diets, 6.3,[17] as summarised in Table 1.

Data analysis

Microsoft Excel (Microsoft, Redmond, WA, USA) was used for statistical analyses including standard deviations for group means. Multiple regressions and correlations were performed using the Minitab Statistical Program (Minitab, State College, PA, USA). Criterion levels of dietary fibre for nutrient claims were determined from the regression equation relating dietary fibre content to WBE_{fb} content, using WBE_{fb} required per 40 g serving to reach the DRV_{fb} on intakes of 16 servings of fibre sources per day, as recommended in the CSIRO12345+ adult food and nutrition plan, and on 10 servings of fibre sources per day, as in the current Australian diet.

Results

Increases in hydrated faecal weight per gram of dietary fibre for wheat bran and wheat bran-rich products in the rat FBI model were in the range of increases in faecal weight per gram of wheat bran fibre observed in humans.[13] The wheat bran reference diet, containing 12.5 g wheat bran/100 g diet caused an increase of 25 g hydrated faecal weight (HFW)/100 g diet, that is, 4.59 g hydrated faeces/g fibre compared with a mean of 5.1 g (SD = 1.34) in 27 human studies.[13] A recent well-controlled metabolic study with humans gave an increase in stool weight per gram of wheat bran dietary fibre of 4.85 g/g fibre,[8] which is very close to the value of 4.59 obtained from the rat FBI model.

Rehydrated faecal bulk was measured with good precision for nearly all of the diets tested (Table 2), as was the increase in hydrated faecal weight/g of diet, which differed considerably between breakfast cereals (range = – 1.7–81.8).

Table 1. Mean wheat bran equivalents (WBE_{fb}) per serving of dietary fibre sources required in various diets to achieve the daily reference value (DRV_{fb}) of 63 WBE_{fb}

Diet	Dietary fibre sources	No. servings of dietary fibre sources	WBE_{fb} requirement per serving (DRV_{fb}/no. servings)
CSIRO12345+ plan[17]	3 fruit + 4 vegetable + 5 cereal	12.0	5.25
CSIRO12345+ plan modified for adults[17]	3 fruit + 4 vegetable + 9 cereal	16.0	3.93
USDA food pyramid[18]	3 fruit + 4 vegetable + 8.5 cereal	15.5	4.10
Current American[18]	0.8 fruit + 1 vegetable + 2.6 cereal	4.4	14.30
Current Australian[17]	2 fruit + 3.5 vegetable + 4.5 cereal	10.0	6.30

USDA, United States Department of Agriculture.

Table 2. Properties of faeces from experimental diets containing 50% breakfast cereal, wheat bran : sucrose 12.5% : 37.5% (reference) or 50% sucrose (baseline)

	HFW (g/100 g feed intake)	Change in HFW (g/100 g feed intake)	Dietary fibre (%)	Increase in hydrated faecal weight/g dietary fibre
Breakfast cereals				
All Bran	73 ± 4.5	51.4 ± 1.7	29.6	3.47
Berry Berry Nice	30 ± 2.3	8.6 ± 1.1	8.5	2.03
Bran Flakes	47 ± 3.9	26.2 ± 1.6	19.1	2.75
Chex	24 ± 1.6	3.3 ± 0.9	1.5	4.36
Cornflakes	19 ± 2.0	–1.7 ± 1.0	3.2	–1.09
Creamoata	33 ± 3.1	12.3 ± 1.3	7.0	3.50
Fruitful porridge	32 ± 4.6	10.5 ± 1.8	8.8	2.40
Fruity Bix	35 ± 2.3	13.8 ± 1.1	9.0	3.06
Just Right	33 ± 1.8	11.8 ± 1.0	8.4	2.80
Kornies	35 ± 6.6	13.4 ± 2.5	11.6	2.31
Miniwheats	34 ± 3.4	13.0 ± 1.4	9.4	2.78
Muesli	38 ± 2.2	17.2 ± 1.1	7.3	4.70
Multiflakes	34 ± 1.7	12.6 ± 1.0	9.8	2.57
Nut Feast	34 ± 2.3	13.0 ± 1.1	9.7	2.68
Nutrigrain	24 ± 1.8	2.7 ± 1.0	3.8	1.45
Oat Bran	29 ± 2.7	7.7 ± 1.2	10.6	1.45
Puffed Rice	21 ± 2.5	–0.4 ± 1.8	5.6	–0.14
Puffed Wheat	30 ± 1.7	8.4 ± 1.0	7.7	2.18
Rolled Oats (Fleming's)	30 ± 5.8	9.0 ± 2.2	6.7	2.69
Rolled Oats (Pam's)	38 ± 6.5	16.9 ± 2.4	9.2	3.67
San Bran	103 ± 14	81.8 ± 5.1	33.6	4.87
Special K	29 ± 1.4	7.5 ± 0.9	3.5	4.27
Sports Plus	36 ± 4.2	15.1 ± 1.7	6.0	5.04
Sultana Bran	42 ± 4.8	20.9 ± 1.9	15.0	2.78
Sustain	32 ± 2.8	10.6 ± 1.2	7.2	2.94
Vita Brits	37 ± 5.3	16.0 ± 2.0	11.6	2.75
Vita Crunch	26 ± 5.0	4.8 ± 1.9	11.0	0.87
Wheat Biscuits	39 ± 1.9	18.0 ± 1.0	10.7	3.36
Reference and baseline				
Wheat bran 12.5% (a)	46 ± 4.7			
Wheat bran 12.5% (b)	46 ± 2.9	25 (Mean)	44.4 (Mean)	4.48 (Mean)
Wheat bran 12.5% (c)	46 ± 11			
Baseline (a)	19 ± 2.0			
Baseline (b)	21 ± 1.3	–	–	–
Baseline (c)	23 ± 1.7			

Mean ± SD; $n = 8$. HFW, hydrated faecal weight.

Faecal bulking increments induced by breakfast cereals

On an equal weight basis, breakfast cereals containing high levels of wheat bran were the most effective faecal bulking agents, and gave FBI values of 81.7 (San Bran), 51.3 (All Bran), 26.2 (Bran Flakes) and 20.2 (Sultana Bran), while the remaining 24 had an FBI of less than 20.

Correlations of faecal bulk with dietary fibre intake

Correlations between faecal parameters and dietary fibre contents of the breakfast cereals are shown in Table 3. As four of the cereals were exceptionally high in fibre (All Bran, 29.6%; San Bran, 33.6%; Bran flakes, 19.1%; Sultana Bran, 15%) and had a large inflationary influence on the *r*-values obtained on data from all cereals ($n = 28$), the analysis of correlation was conducted separately on those that contained less than 15% dietary fibre ($n = 24$), but which nonetheless ranged in fibre content from 3.5 to 11.6%. Most breakfast cereals available to consumers fall into the latter group.

With all breakfast cereals included in the analysis, dietary fibre content correlated strongly and positively with faecal dry matter output per 100 g dietary intake ($r = 0.95$), with water held by the faeces ($r = 0.91$), and with the amount of hydrated faecal output and its increment per 100 g dietary intake ($r = 0.93$). The correlation of faecal water-holding capacity ($r = 0.57$) with dietary fibre was much weaker. When the three products that gave exceptionally large increments in faecal bulk (San Bran, All Bran, Bran Flakes) were excluded from the analysis, by including only cereal products

containing 15% dietary fibre or less, the *r*-values were more representative of the data set but were much reduced, to $r = 0.66$ for dry matter output per 100 g diet, and $r = 0.62$ for hydrated faecal weight and its increment. Water-holding capacity was almost unrelated to fibre content ($r = 0.24$) with the high wheat bran cereals removed.

The inability of dietary fibre levels, in breakfast cereals containing less than 15% dietary fibre as a group, to give a reliable indication of faecal bulking efficacy is shown in Fig. 1.

Breakfast cereal contributions to theoretical daily requirements for faecal bulk

Data used to determine the contribution of breakfast cereals to faecal bulk are given in Table 4. Relative faecal bulking efficacies as WBE_{fb}/g for the breakfast cereals corresponded with their FBI scores, and ranged widely from 37 (San Bran, FBI = 81.7), to –0.52 WBE_{fb} per serving (Cornflakes, FBI = – 1.7). San Bran therefore contributed 59% of the theoretical daily requirement for bulk (63 WBE_{fb}) per serving.

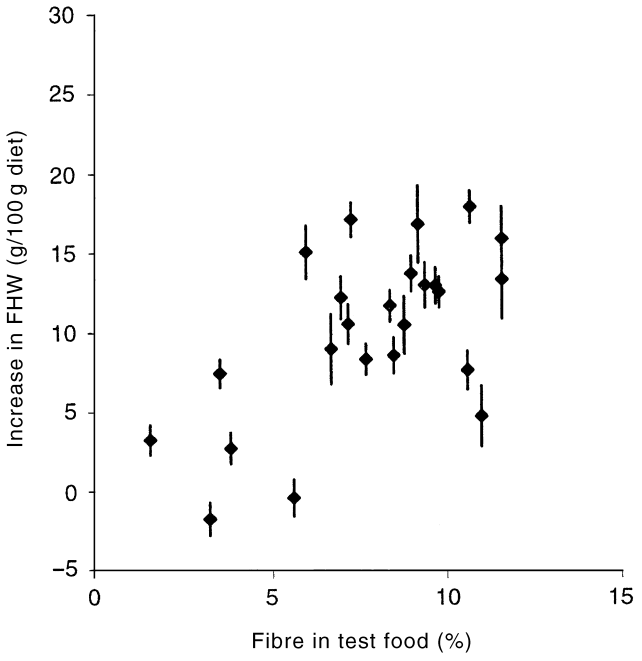

Figure 1. Relationship between dietary fibre content of breakfast cereals that contain less than 15% dietary fibre and increases in rehydrated faecal weight per 100 g diet (mean ± SD). Diets contained 50% breakfast cereals.

The percent contribution of a serving of breakfast cereal to the theoretical DRV_{fb} was calculated and used to rank the breakfast cereals (Table 5). One serving of most of the cereals provided less than 10% of the DRV_{fb} for faecal bulk, but high bran cereals such as San Bran and All Bran provided about half the daily requirement for bulk in a single serving, and about half of the recommended intake of 30 g dietary fibre. All Bran provided 36.7%, San Bran 58.3%, Bran Flakes 12.5%, Muesli 13.6%, Sports Plus 12% and Sultana Bran 14.9% of the DRV_{fb} in a serving.

Rankings of breakfast cereals

Because nutrient claims for dietary fibre are a consumer's guide to laxative efficacy, it is interesting to examine the relative faecal bulking efficacy of breakfast cereals for which nutrient claims relating to dietary fibre have been made. Table 5 shows the percentage of the DRV_{fb} provided per serving of a food, the dietary fibre dose per serving (taken from the nutrition information panel) and associated nutrient claims for dietary fibre based on dietary fibre delivered per serving.

Despite the inconsistent relationship between fibre content and faecal bulking of most breakfast cereals (Fig. 1), nutrient claims for dietary fibre were generally consistent with the ranking of percent DRV_{fb} values; most of the products for which no claim is made contributed little to faecal bulk, and those that contributed greatly to bulk are in the 'high in dietary fibre' and 'very high in dietary fibre' categories.

Classifications of breakfast cereals

The frequency of breakfast cereals occurring in the 'high' categories was much greater when based on nutrient claims ($n = 13$; Fig. 2) than when based on the proportion of the DRV_{fb} provided per serving ($n = 4$; Fig. 3), or on efficacy relative to the range of efficacies measured ($n = 2$; Fig. 4).

Classified by nutrient claims for dietary fibre. The distribution of breakfast cereals and their faecal bulking capacities (WBE_{fb} per serving) across categories of nutrient claims for dietary fibre are shown in Fig. 2. There was a large range in WBE_{fb} per serving within each claim category, and the intervals in the classification were not closely related to the

Table 3. Correlations between dietary fibre content of breakfast cereals fed at 50% of diet and means of faecal bulking responses

Faecal response	All products ($n = 28$) (r)	Products containing <15% dietary fibre ($n = 24$) (r)
Faecal dry matter/100 g feed intake	0.95	0.66
Faecal water/100 g feed intake	0.91	0.54
Hydrated faecal weight/100 g feed intake	0.93	0.62
Increment in hydrated faecal weight/100 g feed intake	0.93	0.62
Water-holding capacity	0.57	0.24

Table 4. Contributions of breakfast cereals to faecal bulk, expressed as wheat bran equivalents for faecal bulk per serving and based on faecal bulking indices

Breakfast cereal	FBI ($100 \times WBE_{fb}/g$)	Serving size (g)	WBE_{fb}/serving (g)
All Bran	51	45	23.1
Berry Berry Nice	8.6	30	2.59
Bran flakes	26	30	7.87
Chex	3.3	30	0.98
Cornflakes	–1.7	30	–0.52
Creamoata	12.2	30	3.67
Fruitful porridge	10.5	40	4.21
Fruity Bix	13.8	40	5.51
Just right	11.7	45	5.28
Kornies	13.4	30	4.01
Miniwheats	13	30	3.91
Muesli	17.2	50	8.58
Multiflakes	12.6	45	5.67
Nut Feast	13	45	5.85
Nutrigrain	2.7	30	0.82
Oat Bran	7.7	30	2.31
Puffed rice	–0.4	30	–0.12
Puffed wheat	8.4	30	2.51
Rolled Oats (Fleming's)	9	30	2.70
Rolled Oats (Pam's)	16.9	30	5.06
San Bran	82	45	36.8
Special K	7.5	30	2.24
Sports plus	15.1	50	7.55
Sultana bran	21	45	9.38
Sustain	10.6	45	4.76
Vita Brits	15.9	30	4.78
Vita crunch	4.8	60	2.87
Wheat biscuits	18	30	5.39
Wheat bran	100	63†	63.00

†Common standard measure = 1 cup. FBI, faecal bulking index; WBE_{fb}, wheat bran equivalents for faecal bulk.

linear range of WBE_{fb} contents of the breakfast cereals. Frequencies of breakfast cereals in the four categories were: low, 10; medium, 4; high 11; and very high, 2. The range of contributions as the percentage DRV_{fb} provided per serving in the various categories were: no claim –0.8–13.6%; 'source of fibre' or 'provides fibre', 3.7–6.2%; 'high in fibre', 7.6–58.3%; and 'very high in fibre', 14.9–36.2% DRV_{fb}/serving, so there was considerable overlap between categories in faecal bulking efficacy.

Classified by contribution to faecal bulk in the CSIRO12345+ plan. The distribution of the breakfast cereals across equal intervals in the CSIRO12345 + plan, based on multiples of the WBE_{fb} per serving required to provide the DRV_{fb}, are shown in Fig. 3. Frequencies of breakfast cereals in the four categories (low, <4; medium, 4–8; high, 8–12; very high, >12) were: low, 12; medium, 12; high, 2; and very high, 2.

If the WBE_{fb} requirement per serving in the current Australian diet had been used to form the categories, the intervals would have been: <6.3, 6.3–12.6, 12.6–18.9, and >18.9, and the frequencies of breakfast cereals in the intervals would have been: low, 22; medium, 4; high, 0; very high, 2.

Classification based on the range of WBE_{fb} contents measured. Figure 4 shows the distribution of the breakfast cereals and their WBE_{fb} content through equal intervals in the range of WBE_{fb} contents per serving observed in the 28 breakfast cereals studied here. Frequencies of breakfast cereals in the four categories (low, <10; medium, 10–20; high, 20–30; very high, >30) were: low, 26; medium, 0; high, 1; and very high, 1.

Contribution of breakfast cereals to faecal bulk in actual and recommended diets

The WBE_{fb} contents per serving of breakfast cereal in various diets needed to meet the DRV_{fb} are shown in Table 6, as is the percentage of the DRV_{fb} per serving that would be required. Comparison of the required percentage DRV_{fb} per serving (Table 6) with the percentage DRV_{fb} per serving measured (Table 5) shows that six of the 28 breakfast cereals would provide the DRV_{fb} (63 WBE_{fb}) if it were provided in the number of servings (10 servings) of dietary

Table 5. Breakfast cereals ranked by contribution of faecal bulk, as percent DRV_{fb} per serving, with corresponding dietary fibre dose per serving, and associated nutrient claims for dietary fibre

	% DRV_{fb}/serving	Fibre per serving (g)	Dietary fibre claim
Wheat bran (1 cup)	100	27.4	NA
San Bran	58	15	'High fibre. Provides half of your daily fibre needs.'
All Bran	37	13	'Very high in fibre.'
Sultana Bran	15	6.7	'Very high in fibre.'
Muesli	14	3.7	No claim
Bran Flakes	13	5.7	'High in fibre.'
Sports Plus	12	3	'High in fibre.'
Nut Feast	9.3	4.4	'Good source of dietary fibre.'
Multiflakes	9	4.4	'High dietary fibre.'
Fruity Bix	8.7	3.6	'…with fibre…'
Wheat Biscuits	8.6	3.2	'High in dietary fibre.'
Just Right	8.4	3.8	'High in fibre.'
Rolled Oats (Pam's)	8	2.8	'High in fibre.'
Sustain	7.6	3.2	'High in fibre.'
Vita Brits	7.6	3.5	'High in fibre.'
Fruitful Porridge	6.7	3.5	No claim
Kornies	6.4	3.5	'High in fibre.'
Miniwheats	6.2	2.8	'Provides fibre.'
Creamoata	5.8	2.1	'Source of fibre. High in complex carbohydrates.'
Vita Crunch	4.5	6.6	No claim
Rolled Oats (Fleming's)	4.3	2	'Source of fibre. High in complex carbohydrates.'
Berry Berry Nice	4.1	2.5	No claim
Puffed Wheat	4	2.3	No claim
Oat Bran	3.7	3.2	'Source of fibre. High in complex carbohydrates.'
Special K	3.5	1.1	No claim
Chex	1.6	0.5	No claim
Nutrigrain	1.3	1.1	No claim
Puffed Rice	–0.2	1.7	No claim
Cornflakes	–0.8	1	No claim

DRV_{fb}, daily reference value for faecal bulk; NA, not applicable.

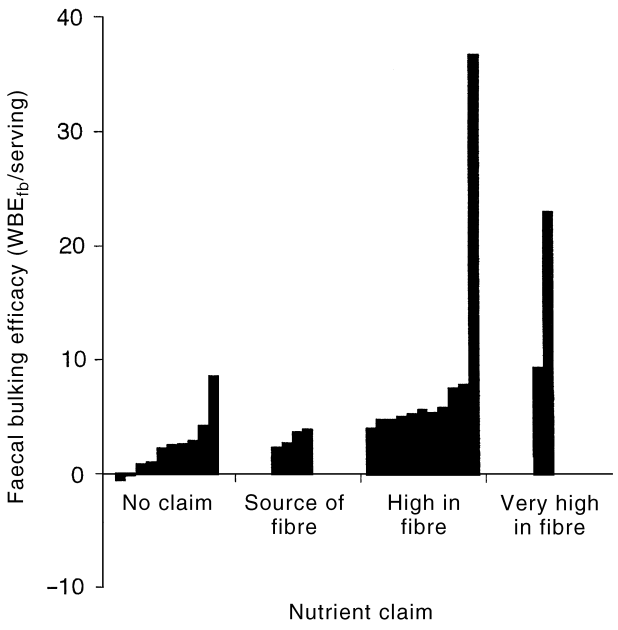

Figure 2. Faecal bulking efficacy (WBE_{fb} per serving) of breakfast cereals classified by nutrient claims. Theoretical daily reference value = 63 WBE_{fb}/day.

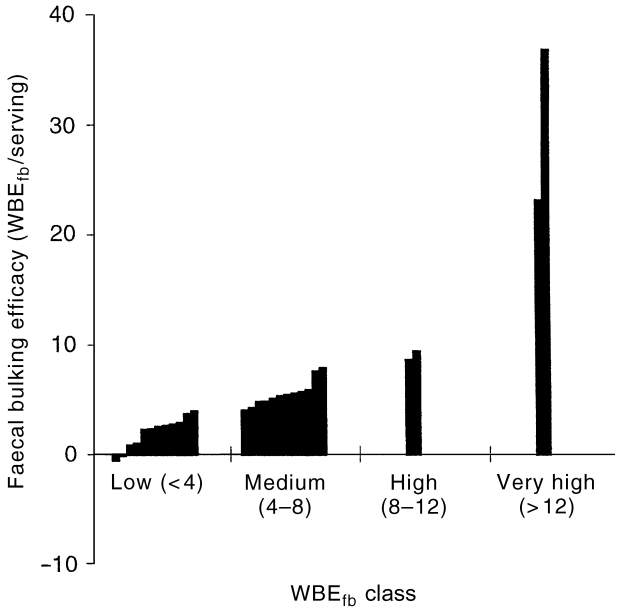

Figure 3. Faecal bulking efficacy (WBE_{fb} per serving) of breakfast cereals in classes based on multiples of the minimum WBE_{fb} per serving (4 g) required to provide the daily reference value (63 WBE_{fb}) on the CSIRO12345+ adult diet (16 servings of fibre sources).

Table 6. Requirements for dietary fibre and faecal bulk, and their provision from current and recommended dietary patterns

	Current food intakes		Food and nutrition guidelines		
	Australia[17]	USA[18]	CSIRO	CSIRO modified	USDA
Servings of dietary fibre sources/day	10	4.4	12	16	15.5
WBE_{fb}/serving required to attain DRV_{fb}	6.3	14.3	5.3	3.9	4.1
Predicted cereal dietary fibre (g)/40 g serving to attain DRV_{fb}	4.35	9.15	3.76	2.92	3.01
%DRV_{fb} required/serving	10	22.7	8.3	6.25	6.45
No. breakfast cereals (n = 28) providing enough bulk to reach the DRV_{fb} in the no. servings/day, above	6	2	11	17	16

CSIRO, Commonwealth Scientific and Industrial Research Organisation; DRV_{fb}, daily reference value for faecal bulk ($63WBE_{fb}$); USDA, United States Department of Agriculture.

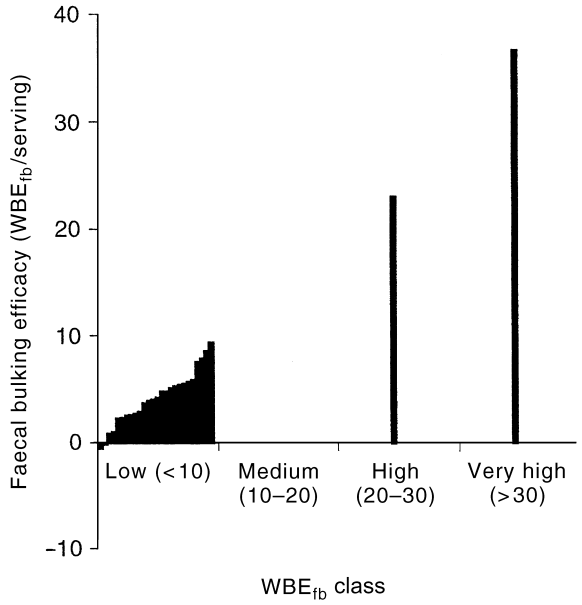

Figure 4. Faecal bulking efficacy (WBE_{fb} per serving) of breakfast cereals classified into approximately equal intervals in the range of faecal bulking efficacies measured (range = – 0.52–36.8).

fibre sources in the current Australian diet, and only three in the current American diet. However, in food and nutrition guidelines such as the CSIRO12345+ adult plan and the USDA plan, which include 15–16 servings of dietary fibre sources, more than half of the breakfast cereals would provide enough WBE_{fb} per serving to supply the DRV_{fb}.

Correspondence of criteria with faecal bulking for nutrition claims

Regression analysis of dietary fibre content as a predictor of WBE_{fb} was carried out after removal of the values for San Bran and Vita Crunch, which had large standardised residuals. The ranges of values for fibre were 1.5–29.6 g/100 g and for WBE_{fb} were –1.7–51. The regression equation obtained was:

$$WBE_{fb}/100\ g = -2.45 + 1.67\%\ \text{fibre};\ R^2 = 0.85 \quad (3)$$

For a 40-g serving the equation becomes:

$$WBE_{fb}/\text{serving} = -0.981 + 1.67\ \text{fibre/serving} \quad (4)$$

Equation 4 was used to predict the amount of faecal bulk, as WBE_{fb}/serving, that corresponded to criterion dietary fibre levels in the food regulations of a number of countries (Table 7). Dietary fibre per serving specified in all food regulations was insufficient to provide the DRV_{fb} within current food consumption patterns, but for UK, USA and Japan, would nearly satisfy requirements (DRV_{fb}) if 15–16 servings of fibre sources were consumed, as recommended in dietary guidelines (Table 7).

Discussion

The rat faecal bulking assay of effects of breakfast cereals was appropriate to assess the role of breakfast cereals in human faecal bulking, judging from the similarity of response to cereal fibre in rats and humans. Increases in rat hydrated faecal weight in response to cereal dietary fibre and water retention by the rehydrated rat faeces were close to human values.[9] As faecal bulk depends largely on monogastric digestion, mixed bacterial fermentation of the residue and water retention by the faecal mass (which occur in both man and rat), the rat is able to show the same relativities between foods as in humans when used in appropriately designed trials,[9] as in the studies presented here. Precision and repeatability in the faecal bulking assay allow confidence that real differences in faecal bulking efficacy were measured. Similarly, prescribed dietary fibre analyses for food labelling are now routinely conducted with good precision (within the laboratory the coefficient of variation is about 5%) so that errors in the dietary fibre values used in this study are likely to have been small.[20]

Faecal increments induced by breakfast cereals

The breakfast cereals analysed were representative of the range available in local supermarkets, and most of them induced only small increases in hydrated faecal weight. Those that contained high levels of wheat bran (San Bran, All Bran, Bran Flakes, Sultana Bran) were highly effective at increasing faecal bulk, while most of the others were much

Table 7. WBE_{fb} content breakfast cereals predicted from criterion levels of dietary fibre used to regulate nutrient claims and requirements to achieve the DRV_{fb} of 63 WBE_{fb} per day

Nutrient claim	Region	Criterion dietary fibre content	WBE_{fb} predicted from criterion dietary fibre content	WBE_{fb}/serving required		Dietary fibre predicted from WBE_{fb} requirement	
				CSIRO12345+	Current	CSIRO12345+	Current
'Source of fibre'	UK, Japan	3 g/100 g	2.56 WBE_{fb}/100 g				
	USA	2.5 g/serving	3.19 WBE_{fb}/serving	3.9	6.3	2.92	4.36
	Australasia	1.5 g/serving	1.52 WBE_{fb}/serving				
'High in fibre'	USA, UK, Japan	6 g/100 g	7.57 WBE_{fb}/100 g				
(2 × 'source of fibre')	USA	5 g/serving	7.37 WBE_{fb}/serving	7.8	12.6	5.26	8.13
	Australasia	3 g/serving	4.03 WBE_{fb}/serving				
'Very high in fibre' (4 × 'source of fibre')	Australasia	6 g/serving	9.04 WBE_{fb}/serving	15.6	25.2	9.92	15.7

CSIRO, Commonwealth Scientific and Industrial Research Organisation; CSIRO12345+, CSIRO12345+ adult diet; Current, current Australian diet; DRV_{fb}, daily reference value for faecal bulk; WBE_{fb}, wheat bran equivalents for faecal bulk.

less effective. The efficacy of products high in wheat bran is to be expected, as wheat bran is relatively resistant to fermentation and is able to retain its space-occupying cellular structure, even after prolonged fermentation under hindgut conditions.[21] Furthermore, wheat bran retains its effectiveness as a faecal bulking agent after being subjected to processes, such as extrusion cooking, that are widely used in the manufacture of cereal products and lead to a reduction in bran particle size.[22] Cereals that had the least impact on faecal bulk were expanded products based on corn and polished rice, and which were therefore high in digestion-susceptible, enzyme-accessible starch, and were low in dietary fibre.

Relationship of faecal bulk to dietary fibre intake

With all of the breakfast cereals included in the analysis a high correlation between dietary fibre content and faecal bulking efficacy of the breakfast cereals was evident (Table 3). However, the statistical correspondence was not close enough at dietary fibre contents of less than 15% for one to be sure that any particular breakfast cereal labelled as 'high fibre' would be highly effective at increasing faecal bulk, because many cereals differing widely in dietary fibre content gave similar increases in faecal bulk (Fig. 1). The results show that dietary fibre cannot be a generally accurate index of faecal bulking for use in food choice for faecal bulk. All cereals in the low fibre group had only modest faecal bulking potential, as all had FBI of less than 20 and provided less than 10% of the DRV_{fb} in a serving.

A close correlation between dietary fibre content and faecal bulking is achievable only when all dietary fibres are equally non-fermentable and enough are present to dominate the effects of variations in other faecal bulking food constituents that are not measured in dietary fibre analysis. In cereals high in wheat bran, dietary fibre effects were both similar and dominant enough for a close relationship between dietary fibre and faecal bulk to emerge, because wheat bran has thick, lignified cell walls that are consequently resistant to fermentation and maintain much of their mass and structure in the colon.

On the other hand, highly fermented food components, such as arabinoxylans and α-glucans of the grain endosperm, pectins and non-lignified primary cell walls of fruit and resistant starch, may be measured in fibre analysis but contribute little to faecal bulk at moderate intakes in a mixed diet.[10,13] Dietary fibre analysis may overestimate faecal bulking in foods containing such non-persistent forms of dietary fibre because, as they are consumed in fermentation, both their intrinsic bulk and their capacity to retain water is lost.

In contrast, many undigested substances that are not measured in dietary fibre analysis may support growth of colonic bacteria in the gut, and will also contribute to variation in the relationship between dietary fibre and colonic bulk through their different effects on faecal mass.[8] Such non-digestible food components include entrapped resistant starch and protein, non-digestible protein–carbohydrate

conjugates, short-chain polysaccharide fragments, Maillard products, and many others.[8] Low correlations between dietary fibre content and faecal bulk for the breakfast cereals that contained less than 15% dietary fibre may have resulted from differing food process and ingredient matrix interactions during manufacture, producing such compounds that contributed to faecal bulk, but had not been measured in the Association of Official Analytical Chemists International's dietary fibre analysis,[23] within a matrix with a low background content of dietary fibre.

Differences in hydration properties of the dietary fibres in the breakfast cereal set examined here were probably not a factor influencing the lack of correspondence between hydrated faecal weight and dietary fibre content at low fibre levels, because the faecal water-holding capacity of the cereals did not differ greatly.[9] Highly hydrated polysaccharide networks and gels would have been unlikely to form in the rehydrated faeces because cereal soluble fibres are highly susceptible to bacterial degradation in the hind gut and rapidly lose their hydration and rheological properties upon chain cleavage.

Correspondence between nutrient claims for dietary fibre and provision of faecal bulk

When the frequencies of the breakfast cereals in classes based on dietary fibre content and nutrient claims (Fig. 2) are compared with their frequencies in classes based on ability to supply the DRV_{fb} (Fig. 3) or on the range of faecal bulking efficacies measured (Fig. 4), a lack of correspondence between the three classifications is seen.

The differing effects of different fibres on faecal bulk and the uncertain physiological meaning of results from dietary fibre assays for food labelling creates the potential for inconsistencies between classes based on dietary fibre rather than on physiological effect. Classification of breakfast cereals into equal intervals based on faecal bulking, rather than on dietary fibre content, and covering the continuous range of faecal bulking efficacies would reflect the consistent relationship between food properties and function better than the present classification based on dietary fibres, especially for cereals containing less than 15% dietary fibre. For cereals of reasonably high fibre content, a positive linear relationship exists between cereal intake and faecal bulking.[9] The present results suggest that in the case of wheat bran-based cereals with about 15% or more dietary fibre, classification by faecal bulking is likely to parallel changes in fibre content.

Comparison of Figs 2–4 shows not only that the current standards for health claims relating to dietary fibre may be unhelpful to food choice for faecal bulk, but also that a large number of breakfast cereals are ineffective faecal bulkers. Given that the products analysed were fairly representative of those available in supermarkets, it seems that too few of them are of moderate or high faecal bulking capacity to justify the general reputation of breakfast cereals as being exceptionally good at satisfying daily fibre needs. Thus, nutrition claims for dietary fibre imply a greater effectiveness than is suggested by the functional efficacy data for the foods.

Estimated contribution of breakfast cereals to actual and recommended diets

Estimates of the average contribution of WBE_{fb} per serving of dietary fibre sources that would be needed to supply the DRV_{fb} in the different diets, are given in Table 6. In diets that followed the CSIRO12345+, CSIRO1233345+ adult and USDA nutrition guidelines, many of the breakfast cereals would contribute enough dietary fibre per serving of fibre source to supply the DRV_{fb}. However, on current food intakes, many of them would not reach the threshold value of 6.3 WBE_{fb} per serving needed to maintain adequate faecal bulk in Australia, and in the USA diet very few would be able to compensate for the inadequate intakes of dietary fibre sources.

Adequacy of current criteria for nutrient claims for dietary fibre

Using regression Equation 4, with dietary fibre as a predictor of WBE_{fb}, it was possible to test the adequacy of criteria currently used to make nutrient claims for dietary fibre in breakfast cereals. WBE_{fb} loadings were predicted from criterion levels of fibre and compared with multiples of the base requirement of 3.9 WBE_{fb} per serving of dietary fibre sources per day in the CSIRO12345+ adult diet, and 6.3 WBE_{fb} in the current Australian diet. The fibre contents required for claims 'source of fibre' and 'high in fibre' in the UK, USA and Japan would be reasonably close to multiples of requirements if the populations were consuming 15–16 servings of fibre sources in accordance with the CSIRO12345+ adult plan or USDA guidelines. However, if the aim of the regulations was to promote health within the current Australian diet, which contains 10 servings of fibre sources, the criterion fibre levels would be too low.

Appropriate criterion levels of dietary fibre for nutrient claims

Rearranging Equation 4 to make WBE_{fb} a predictor of dietary fibre allowed calculation of dietary fibre levels corresponding to the WBE_{fb} intakes identified as adequate in Table 6. In Table 6 it was shown that in an adequate diet such as the CSIRO12345+ modified plan, in which 16 servings of dietary fibre sources are consumed daily, the WBE_{fb} levels required per serving to reach the DRV_{fb} were 3.9 WBE_{fb}. Table 7 shows the dietary fibre levels per 40 g serving that would correspond to the criterion levels of 3.9 WBE_{fb} for 'source of dietary fibre', $2 \times 3.9 = 7.8$ WBE_{fb} for 'high in dietary fibre, and $4 \times 3.9 = 15.6$ WBE_{fb} for 'very high in dietary fibre', using the same multiples as in the ANZFA food standards. The dietary fibre values corresponding to WBE_{fb} requirements were much greater than the current criterion values for dietary fibre used in Australasian food regulations, which therefore appear to be too low. For nutrient claims to be consistent with efficacy, criterion values for dietary fibre would need to be more than doubled

from present standards to ensure that the current Australian diet would meet requirements.

Increases in faecal bulk induced by cereals and other foods resulted from changes in faecal dry matter output, greatly amplified by retained water, as the water holding capacity of faeces from all breakfast cereals was approximately 2 g/g dry faecal matter in diets containing 50% breakfast cereal.[9] The health benefits that might result from such increases in water activity, and correspondingly reduced chemical potential in the distal colon, justify the development of food descriptors to reflect such changes. FBI, WBE_{fb} and food regulations based on the faecal bulking response would be scientifically appropriate, but may need to be expressed in terms of dietary fibre to be consistent with current food labelling practices.

Although a significant relationship between dietary fibre content and faecal bulking in breakfast cereals as a group allowed faecal bulk to be used to predict dietary fibre levels appropriate for nutrient claims, it was also clear that at low dietary fibre levels, dietary fibre content could not be used with confidence to select any given cereal on the basis of faecal bulking efficacy. The dietary fibre contents identified as appropriate for nutrient claims for breakfast cereals all lay within the <15% fibre region, in which dietary fibre was a poor predictor of faecal bulk.

In view of the probable importance of distal colonic bulk as a factor mediating the health benefits of cereal-based foods and fibres,[24,25] other direct indictors of faecal bulking, such as WBE_{fb}, may be more appropriate than dietary fibre content per se for describing the faecal bulking efficacy of foods.

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