Original Article

Faecal bulking efficacy of Australasian breakfast cereals

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Faecal bulk may play an important role in preventing a range of disorders of the large bowel, but as yet there is little information available on the relative faecal bulking capacities of various foods. Breakfast cereals are often promoted as a good source of potential bulk for 'inner health' because they provide dietary fibre, but their relative abilities to provide faecal bulk per se have not been described. The faecal bulking efficacy of 28 representative Australasian breakfast cereals was therefore measured. A rat model developed for the purpose, and shown to give similar responses as humans to cereal fibres, was used to measure faecal bulking efficacy as increases in fully hydrated faecal weight/100 g diet, based on precise measurements of food intake, faecal dry matter output and faecal water-holding capacity (g water held without stress/g faecal dry matter). Compared to a baseline diet containing 50% sucrose, increments in hydrated faecal weight due to 50% breakfast cereal ranged from slightly negative (Cornflakes, –2 g/100 g diet) to about 80 g/100 g diet (San Bran). Most breakfast cereals increased hydrated faecal weight by between 10 and 20 g/100 g diet from a baseline of 21 ± 1.5 g/100 g diet, but four products containing high levels of wheat bran had an exceptionally large impact on hydrated faecal weight (increment >20 g/100 g diet), and the changes resulted more from relative changes in dry matter output than in faecal water retention/gram. However, as faecal water retention was about 2.5 g water/g faecal dry matter on average, increases in dry matter represented large increases in faecal water load. Faecal bulking indices (FBI) for most of the breakfast cereals were less than 20 (wheat bran = 100). The content of wheat bran equivalents for faecal bulk (WBE_{fb}) in the breakfast cereals was calculated from FBI. Most breakfast cereals contributed, per serve, less than 10% of a theoretical daily reference value for faecal bulk (DRV_{fb} = 63 WBE_{fb}/day), which was based on data from human clinical trials and dietary fibre recommendations. Based on the WBE_{fb} contribution/serving that would be required to meet the DRV_{fb} from the number of servings of dietary fibre sources in the CSIRO 12345+ food and nutrition plan, the results suggest that although some high bran breakfast cereals may contribute substantially to, and many are reasonable sources of, faecal bulk, for most of them, one or two servings at breakfast cannot be relied on to effectively redress shortfalls in faecal bulk elsewhere in the diet.

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

Introduction

Breakfast cereals are commonly promoted as valuable in maintaining large bowel health because they contribute dietary fibre to the diet. Certainly, a cereal-based breakfast could provide a good proportion of the daily requirements of potential faecal bulk, if it contained appropriate foods. But the relative ability of a wide range of breakfast cereals to increase faecal bulk has not yet been measured with a standardized test to obtain comparative data that would allow evidence-based selection for faecal bulk.

Although dietary fibre values are given in nutrition information panels, the dietary fibre content of a food on its own is often an inadequate guide to its faecal bulking action because faecal bulk depends on bacterial biomass, undigested and unfermented food residues (of which dietary fibre is one component) and the water-holding capacity of the whole faecal mass.[1]

The faecal bulking efficacy of foods is important because bulk is a dominant factor promoting the transit of prefaecal and faecal matter through the large bowel. Increased rate of transit may protect against a range of large bowel disorders by ensuring constant throughput of moist faecal bulk, reducing dehydration and hardening of the faecal mass, preventing colonic stagnation with putrefactive production of nitrogenous and other toxins, and replenishing substrates for bacterial production of butyrate or other beneficial products.[2] The importance of faecal bulk in the relief of common, simple constipation is well known, and is of concern to a large number of people who rely on nutrition advice to help them to select appropriate foods to prevent constipation and related disorders. At present, consumers have only dietary fibre values to guide them.

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A standardized faecal bulking index (FBI) has been developed recently as a physiological basis for assessing the faecal bulking efficacy of foods for dietary management of faecal bulk.[3] The FBI of a food or other material is defined as the increment in fully hydrated faecal bulk induced by the food as a percentage of that induced by an equal amount of wheat bran reference, and it is measured with an appropriately configured rat model. By using wheat bran as a reference material in the FBI assay, the faecal bulking efficacy of any quantity of any food for which an FBI value has been determined can be expressed as its content of wheat bran equivalents for faecal bulk (WBE_{fb}). WBE_{fb} allow foods to be compared easily in terms of a familiar reference material (i.e., wheat bran) and faecal bulking efficacy to be communicated in terms of the effects of familiar quantities, such as servings.[4]

This paper presents the results of applying the FBI assay to 28 Australasian breakfast cereals. The FBI values obtained were used to determine the content of wheat bran equivalents in the breakfast cereals. This allowed the estimation of the faecal bulk derived daily from a standard serving of these foods, compared to a daily reference value representing an average, adult, daily requirement for intake of potential faecal bulk.

Methods

Samples

The breakfast cereals subjected to the faecal bulking assays reported here were chosen to cover much of the range of cereal types available in New Zealand supermarkets, and many of them were also made and sold in Australia. The same types of sample that differed only in flavour, such as chocolate and plain rice bubbles, or in manufacturer, as in numerous brands of rolled oats and muesli, were not usually duplicated. The following breakfast cereals were obtained from local supermarkets for faecal bulking analysis: 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). All breakfast cereals and the wheat bran reference were milled to pass through a 2-mm sieve.

Dietary fibre values. Dietary fibre values used were obtained from the nutrient information panels on the cereal packets or, where not available, from the New Zealand Food Composition Database.[5] Reliance on such fibre data is justified in the context of this paper, which investigates the relationship between effects of cereal products and the dietary fibre values on which consumers base their expectations of food effects.

Test diets

Breakfast cereals. Diets were based on a standard powdered rat diet normally containing 650 g/kg of starch (Table 1). For faecal bulking assays, 550 g of the starch was replaced by 50 g of fibre mix plus 500 g of test component for measurement of FBI. The test components for the various diets were:

Table 1. Composition of diets used to assess faecal bulking efficacy of Australasian breakfast cereals

	Baseline (g dry weight/kg)	Reference (g dry weight/kg)	Breakfast cereal (g dry weight/kg)
Diet base			
Casein	200	200	200
Salt mix	50	50	50
Vitamin mix	50	50	50
Fibre mix	50	50	50
Corn oil	50	50	50
Wheat starch	100	100	100
Variable			
Wheat bran	–	125	–
Sucrose	500	375	–
Test food/fibre	–	–	500

Fibre mix: Wheat bran : pectin (4:1). Contains insoluble : soluble fibre at about 3:1. The wheat bran is about 50% non-starch polysaccharide and is milled to 0.25 mm. Apple pectin (Mexpectin) is the pectin source. Cellulose (185.7 g/kg) in the salt mix, consisting of 7.74 g in the trace element mix and 178 g/kg q.s. adds a further 0.05 × 185.7 = 9.3 g cellulose/kg diet. Mineral mix (g/kg salt mix): $CaHPO_4$ 427; MgO 35; KCl 200; NaCl (iodized) 100; trace element mix 60; cellulose q.s (178). Trace element mix (g/kg trace salt mix): $C_6H_5O_7Fe.3H_2O$ 756.7; ZnO 20; $CuCO_3.Cu(OH)_2.H_2O$ 6.7; $MnSO_4.H_2O$ 80; Na_2SeO_3 0.11; $CoCl_2.6H_2O$ 0.039; $CrK(SO_4)_2.12H_2O$ 6.3; KIO_3 0.085; $(NH)_4MO_7O_{24}.4H_2O$ 0.093; cellulose q.s. Vitamin mix (g/kg mix): Retinyl acetate (500 000 IU/g) 0.1; tocopherol (Roche, France; Rovimax E-25 250 000 IU/g) 4.0; menadione 0.06; ergocalciferol (20 000 IU/g); 1/100 in sucrose pre mix 0.05; thiamin.HCl 0.1; riboflavin 0.14; pyridoxine.HCl 0.16; calcium pantothenate 0.4; folic acid 0.04; nicotinamide 0.4; cyanocobalamin (1/100 in sucrose pre mix) 0.1; biotin 0.02; myo-inositol 4.0; choline chloride 30.0; sucrose q.s. Wheat bran reference: Proximate composition (%): Moisture, 10.6; protein, 14.6; fat, 1.8; available carbohydrate, 26.1; dietary fibre (Prosky), 43.5; ash, 5.7.

for the baseline diet, 500 g sucrose; for the reference diet, 125 g wheat bran plus 375 g sucrose; and for the breakfast cereal diets, 500 g cereal, which completely replaced the sucrose in the baseline diet. All diets, except for the original standard diet, contained a basal level of 3.67% mixed dietary fibres, provided by the 50 g/kg fibre mix (Table 1), plus 9.3 g cellulose/kg diet, present in the mineral mix. The fibre was included to ensure a normal gut with an abundant and diverse hindgut flora, and rapid clean-out upon changing diets. The 12.5% wheat bran reference diet provided 5.44% dietary fibre in addition to the 3.67% fibre in the baseline diet. The composition of the diets is summarised in Table 1.

Cereal fibre: faecal bulk dose–response relationship. The linearity of faecal bulking response to processed cereal fibre was measured in a trial containing rat groups (n = 5) fed a series of diets based on All Bran, and formulated to provide 2.5, 5, 7.5, 10, 12.5 and 15% processed wheat bran fibre in addition to the 3.67% baseline fibre.

Animals

Adult male Sprague-Dawley rats (400 ± 50 g) were housed individually in hanging wire-bottom cages in a controlled environment room (light, 12 h; dark, 12 h; temperature 23 ± 2°C; humidity 50–60%). Eight rats/group were used for the faecal bulking assay of breakfast cereals. The rats were assigned to 64 cages in repeating eight-rat blocks for each set of trials. Each block contained a rat from the baseline, reference and each of the six diet groups in every run. Between each set of diets the rats were rotated to new positions within each block in a staggered manner to ensure that no two rats in a trial had been in the same diet group in a previous run, to avoid any systematic influence of preceding diets. Fully grown rats were used because of their relatively large matured gut and also because they readily consumed food particles up to about 2 mm diameter, which allowed food structure to be preserved. Use of the animals for measurement of faecal bulking was approved by the Crown Research Institutes' Animal Ethics Committee.

Trial procedure

Trials were not started until all animals were willing and able to consume 25 g baseline diet/day. Faecal bulking assays of breakfast cereals required 11 days with eight rats/diet group. In the lead-in period of the first three days (days 1, 2 and 3), all groups were fed the baseline diet. Over the following seven days, one group continued on the baseline diet, one group was fed the reference diet and the remaining groups were fed the trial diets. During the seven-day period in which the test diets were fed to the rats, the first three days (days 4, 5 and 6) were treated as a clean-out period, and the last four (days 7, 8, 9 and 10) as providing the intakes that contributed the faeces collected on the morning of days 8, 9, 10 and 11.

Feed intakes

The daily feed ration was restricted to 25 g/rat (100 g diet for the four-day balance period), which was usually consumed completely, apart from spillage, in order to standardise intakes and keep them well within the functional capacity of the gastrointestinal tract. The diets were weighed into glass jars in fixed stainless steel pot holders located in a cage corner, which almost eliminated contamination of faeces by spilt feed. Spillage and accumulated refusals were weighed at the end of the balance period so that feed intake could be calculated accurately. In most cases, over 90% of the feed was consumed.

Faecal collections

Faeces from each rat were collected on a double thickness of blotting paper placed on a thin layer of fresh sawdust beneath the cages at the start of the balance period. They were picked cleanly from the paper each morning of the collection period, placed into individually labelled specimen containers and allowed to air dry in the trial room. On completion of the balance period, the accumulated faeces were dried overnight in a warm (45°C) vacuum oven connected to a freeze drier, to obtain a value for faecal dry matter output.

Faecal rehydration

Between two and three grams of intact, dry faecal pellets were weighed accurately into preweighed 75 mL specimen jars, 3 mL of water added, and the pots placed in a refrigerator overnight for the faeces to rehydrate. Full rehydration is usually achieved within 6 h. The following morning, the 3 mL of water had been completely absorbed and an additional 4 mL was added to saturate the faecal pellets. After allowing them to stand for 1 h, any excess water was sucked off with a Pasteur pipette, the pots were placed on a slope and any moisture draining from the pellets over a period of 30 min was sucked off. The pots containing the rehydrated pellets were then reweighed to determine hydrated faecal weight (HFW).

Calculations

The faecal water-holding capacity (FWHC) of the rat faeces was calculated as water uptake/gram dry weight of faecal matter. Rehydrated faecal output/100 g feed was calculated as HFW/g faeces × total faecal output × 100/feed intake. Faecal bulking indices were calculated for the breakfast cereals, on an as is, unmodified basis, as the mean increase in hydrated faecal bulk due to a food, as a percentage of the increase due to consumption of an equal weight of the wheat bran reference:

$$\text{FBI} = \frac{\text{Increase over baseline in mass of rehydrated faeces/g of test food consumed}}{\text{Increase over baseline in mass of rehydrated faeces/g of reference food consumed}} \times 100$$

The following formula was used to calculate FBI:

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

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

As they are indices, FBI values cannot be directly related to food quantities, but they may be used to determine the weight of a reference of known FBI, such as wheat bran, that gives the same faecal bulking as a given weight of another food of known FBI. Bulking efficacy may then be expressed as the content of reference equivalents in the food. By using wheat bran as the reference for both determination of FBI and for food comparisons, faecal bulking efficacy could be expressed as the WBE_{fb} content/gram of the food, and calculated simply as FBI/100.[4] The WBE_{fb} content/serving of breakfast cereal was then calculated using serving sizes given in the nutrition information panels on the breakfast cereal packets.

Derivation of a daily reference value for faecal bulk

To assess the ability of the breakfast cereals to contribute to requirements for faecal bulk, a theoretical reference value for daily intake of potential faecal bulk was calculated in WBE_{fb}. This daily reference value for faecal bulk (DRV_{fb}) was based on the reference daily intake of 30 g dietary fibre, used in the proposed Australia New Zealand Food Standards Code,[6] and on information in the New Zealand Food Composition database that one standard 250 mL cup of wheat bran, which weighs 63 g, provides 27.4 g of dietary fibre.[5] The value 27.4 g is almost exactly the mean of the often recommended intakes of 30 g dietary fibre for men and 25 g for women. On this basis, 63 g of wheat bran equivalents should, on its own, satisfy the daily requirement for dietary fibre and faecal bulk.

A DRV_{fb} of 63 WBE_{fb} is consistent with data from a large number of studies showing that 1 g wheat dietary fibre causes a mean increase in faecal weight of 5.11 ± 1.34 g in humans (30 studies, three outliers removed),[7] and that 150 g faecal output/day is associated with prevention of large bowel disease in Australians.[8] As wheat bran is 0.435% dietary fibre, the weight of wheat bran required to increase faecal bulk by 150 g is $150/(5.11 \times 0.435) = 67.5$ g wheat bran.

The DRV_{fb} of 63 WBE_{fb} is to allow realistic comparisons to be made between cereal products, although, in reality, differences between the WBE_{fb} requirements of individuals will be large.

Data analysis

Microsoft Excel was used for calculation of means and standard deviations, and for graphics. Multiple regressions were performed using the Minitab Statistical Program (Minitab, State College, PA, USA).

Results

Faecal bulking increments induced by breakfast cereals

Increments in hydrated faecal weight due to replacement of 500 g/kg sucrose from the baseline diet by 500 g/kg of breakfast cereal (Table 1) are shown in Fig. 1, in which the breakfast cereals are ranked in order of the increment in faecal bulk that they induced. The ranking shows that, on an equal weight basis, breakfast cereals containing high levels of wheat bran were the most effective faecal bulking agents, but that most of the other breakfast cereals increased faecal bulk by between 10 and 20 g/100 g diet. 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.

Contribution of dry matter and water holding to increments in faecal bulk

The dominant factor determining the ability of the breakfast cereals to increase hydrated faecal bulk over baseline was the change in faecal dry matter, rather than differences in the water-holding capacity of the faecal mass. The range of increments in faecal dry weight values was accordingly much greater than the range of increments in FWHC. Faecal dry weight/100 g diet ranged from 7.1 g (Cornflakes) to 26.5 g (San Bran; Table 2), a 273% difference (sucrose baseline value = 6.8 g), whereas faecal water retention ranged from 1.69 g water/g (Oat Bran and Fleming's Rolled Oats) to 2.87 g water/g (San Bran), a 70% difference (FWHC of baseline diet = 2.12). As a percentage of rehydrated faecal weight, water content ranged between only 63 and 74% (faeces from baseline diet = 67.9%).

From data based on equal intakes of breakfast cereals at 50% of the diet, the impact of products high in wheat bran can be attributed mainly to their large effects on faecal dry matter (Fig. 2) and, to a lesser extent, to their effects on faecal water-holding capacity (Fig. 3). Despite the small differences in faecal water-holding capacity for most breakfast cereals, the changes in faecal dry matter led to large

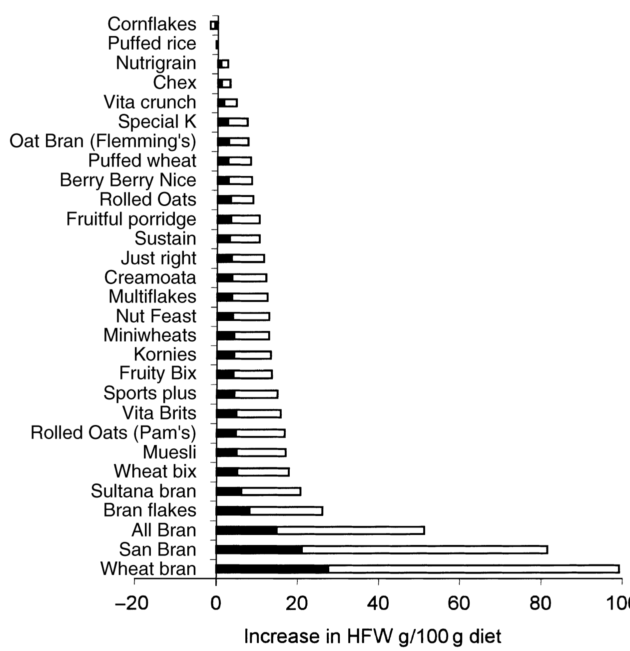

Figure 1. Breakfast cereals ranked according to the increase in hydrated faecal weight (HFW) over baseline that they induce, with the breakfast cereals included at 50% of the diet. (■) faecal dry matter; (□) faecal water. Baseline HFW = 21 ± 1.7 g/100 g diet.

Table 2. Properties of faeces from rats fed experimental diets containing 50% breakfast cereal, or 12.5% wheat bran: 37.5% sucrose (reference), or 50% sucrose (baseline) (mean ± SD; *n* = 8)

	Faecal dry weight (g/100 g feed)	Faecal water holding capacity (g water/g faeces)	Water content of rehydrated faeces (%)	Change in faecal water/ (g/100 g feed (%)	Rehydrated faecal weight (g/100 g feed intake)
Breakfast cereals					
All Bran	20.8 ± 1.8	2.44 ± 0.11	71.0	253.9	73 ± 4.5
Berry Berry Nice	9.7 ± 0.5	2.07 ± 0.13	67.4	39.4	30 ± 2.3
Bran Flakes	14.6 ± 1.0	2.20 ± 0.11	68.7	122.5	47 ± 3.9
Chex	7.6 ± 0.2	2.22 ± 0.13	68.9	16.9	24 ± 1.6
Cornflakes	7.1 ± 0.5	1.77 ± 0.12	63.9	–12.8	19 ± 2.0
Creamoata	10.4 ± 0.5	2.22 ± 0.15	68.9	59.8	33 ± 3.1
Fruitful porridge	10.2 ± 1.0	2.10 ± 0.17	67.8	48.8	32 ± 4.6
Fruity Bix	10.7 ± 0.5	2.27 ± 0.15	69.4	68.5	35 ± 2.3
Just Right	10.3 ± 0.3	2.19 ± 0.16	68.7	57.2	33 ± 1.8
Kornies	10.9 ± 2.4	2.08 ± 0.09	67.6	58.6	35 ± 6.6
Miniwheats	11.2 ± 0.5	2.00 ± 0.23	66.7	55.6	34 ± 3.4
Muesli	11.2 ± 0.5	2.43 ± 0.10	70.8	88.7	38 ± 2.2
Multiflakes	10.1 ± 0.5	2.33 ± 0.07	70.0	64.3	34 ± 1.7
Nut Feast	10.4 ± 0.5	2.29 ± 0.09	69.6	65.2	34 ± 2.3
Nutrigrain	8.3 ± 0.6	1.88 ± 0.10	65.3	8.6	24 ± 1.8
Oat Bran	10.4 ± 0.8	1.69 ± 0.14	62.9	23.0	29 ± 2.7
Puffed Rice	7.1 ± 1.0	1.83 ± 0.11	64.6	–10.2	21 ± 2.5
Puffed Wheat	9.8 ± 0.7	2.07 ± 0.07	67.4	41.3	30 ± 1.7
Rolled Oats (Fleming's)	10.9 ± 1.9	1.69 ± 0.11	62.9	28.4	30 ± 5.8
Rolled Oats (Pam's)	10.7 ± 1.2	2.53 ± 0.31	71.7	88.7	38 ± 6.5
San Bran	26.5 ± 3.1	2.87 ± 0.19	74.2	430.2	103 ± 14.3
Special K	10.1 ± 0.4	1.83 ± 0.07	64.6	28.6	29 ± 1.4
Sports Plus	10.7 ± 0.6	2.39 ± 0.26	70.5	77.4	36 ± 4.2
Sultana Bran	12.4 ± 1.5	2.39 ± 0.08	70.5	106.1	42 ± 4.8
Sustain	9.5 ± 0.9	2.35 ± 0.09	70.1	54.9	32 ± 2.8
Vita Brits	11.4 ± 1.8	2.26 ± 0.11	69.3	79.2	37 ± 5.3
Vita Crunch	8.8 ± 1.8	1.82 ± 0.09	64.6	11.5	26 ± 5.0
Wheat Biscuits	11.5 ± 0.3	2.40 ± 0.12	70.6	91.9	39 ± 1.9
Reference and baseline					
Wheat bran 12.5% (a)	12.7 ± 1.5	2.63 ± 0.15	72	133.2	46 ± 4.7
Wheat bran 12.5% (b)	12.3 ± 0.5	2.74 ± 0.15	73	134.6	46 ± 2.9
Wheat bran 12.5% (c)	13.1 ± 1.9	2.51 ± 0.45	71	128.3	46 ± 11.1
Baseline (a)	6.6 ± 0.6	1.95 ± 0.10	66	–	19 ± 2.0
Baseline (b)	6.6 ± 0.4	2.21 ± 0.15	69	–	21 ± 1.3
Baseline (c)	7.1 ± 0.2	2.20 ± 0.20	69	–	23 ± 1.7

changes in water loading/100 g diet, because every gram of dry matter has the capacity to hold about 2.5 times its weight in water (Table 2). For instance, 50% San Bran in the diet caused an increase of over 400% in held water/100 g feed intake, but most breakfast cereals increased the amount of water held by between 20 and 80%, and two cereals (Cornflakes and Puffed Rice) decreased the water load. Thus, because the total water retained/100 g diet intake increased in parallel with increases in faecal dry matter, the increase in water activity/100 g diet, caused by bran-enriched breakfast cereals in particular, was considerable, as is seen in Fig. 1, which separately shows the dry matter and moisture contributions to the increase in hydrated faecal weight.

The wheat bran-enriched cereals had a large impact on the characteristics of the data set, inflating the correlation of the increment in hydrated faecal weight (IncHFW) with faecal dry weight and water-holding capacity, and causing a non-linearity in the relationship between IncHFW and FWHC (Figs 2,3). After removing the four high-wheat bran cereals (San Bran, All Bran, Bran Flakes and Sultana Bran) from the data set, the range in faecal dry weight (FDW)/100 g diet was 7.1 g/100 g (Cornflakes) to 12.4 g/100 g (Sultana Bran), a 75% difference, and the FWHC range was from 1.69 g water/g (Oat Bran and Fleming's Rolled Oats) to 2.53 g water/g (Pam's Rolled Oats), a 50% difference.

The relationship of increments in hydrated faecal weight (IncHFW)/100 g diet, to FDW/100 g feed intake, and to faecal water-holding capacity (FWHC, g water/g dry faeces), determined by regression analysis of the group means with the four high-wheat bran cereals removed, were:

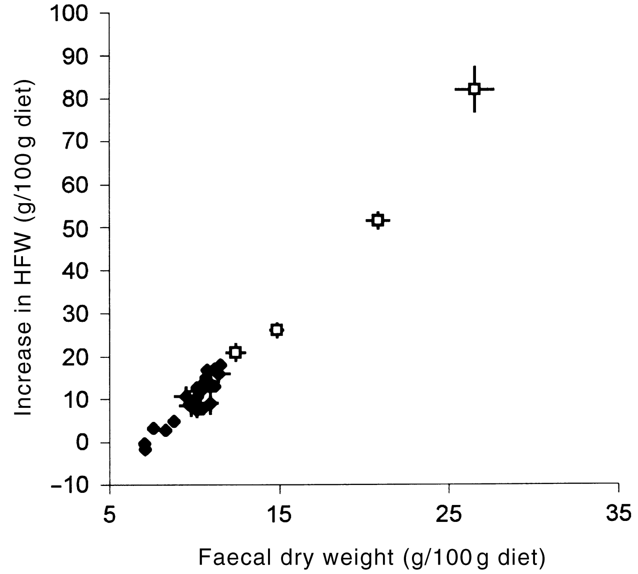

Figure 2. Relationship between faecal dry matter and increase in hydrated faecal weight (HFW) for diets containing 50% breakfast cereal (□) Samples high in wheat bran (All Bran, San Bran, Bran Flakes, Sultana Bran); (◆) all other samples. Means ± SEM.

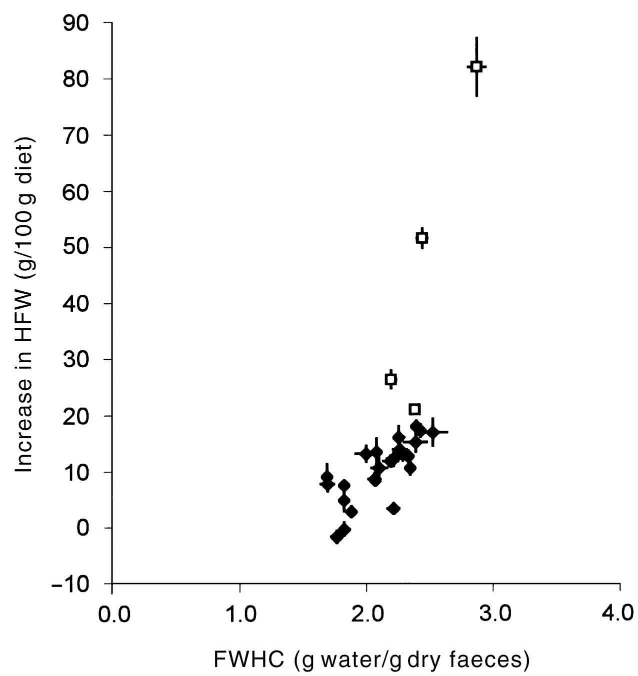

Figure 3. Relationship between faecal water-holding capacity (FWHC) and increase in hydrated faecal weight (HFW) for diets containing 50% breakfast cereal. (□) Samples high in wheat bran (All Bran, San Bran, Bran Flakes, Sultana Bran); (◆) all other samples. Means ± SEM.

with FDW as a predictor,

$$\text{IncHFW} = -28 + 3.84\ \text{FDW}\ (R^2 = 0.84)$$

with FWHC as a predictor,

$$\text{IncHFW} = -25.1 + 16.7\ \text{FWHC}\ (R^2 = 0.56)$$

using FDW and FHW as predictors,

$$\text{IncHFW} = -39.9 + 3.02\ \text{FDW} + 9.45\ \text{FWHC}\ (R^2 = 0.99)$$

Faecal bulking indices and wheat bran equivalents for breakfast cereals

Faecal bulking index, the increment in hydrated faecal bulk induced by a food as a percentage of the increment due to an equal weight of wheat bran (Table 3), expresses the relative faecal bulking efficacy of foods on an as is, equal weight basis.[3] The FBI values derived here are based on the mean increment in HFW/100 g diet induced by a breakfast cereal, divided by the mean increment due to the wheat bran reference, adjusted for the relative content of wheat bran in the reference diet.

Because wheat bran was used as a reference both for the measurement of FBI and for the comparison of the relative faecal bulking capacities of the foods based on their FBI scores, the WBE_{fb} content/gram of food could be taken simply as FBI/100. The FBI values, serving weights and WBE_{fb} contents/serving of the breakfast cereals are given in Table 3.

Breakfast cereal contributions to theoretical daily reference value for faecal bulk

The percentage contribution of a serving of fibre to the theoretical DRV_{fb} of 63 WBE_{fb}/day was calculated and is shown in Table 4. 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.

Comparison of responses to cereal fibre in humans and in the rat model

The increases in HFW/g of breakfast cereal dietary fibre consumed by the rats were calculated and compared with published increases in faecal weight/g of wheat fibre consumed by humans.[6] The results (Fig. 4) show a reasonable correspondence between the rat and human models, once the rat faeces are allowed to passively hydrate, so that the rehydrated faecal bulk depends solely on faecal dry matter content and its ability to retain water without physical stress, which defines water-holding capacity.

Linearity of faecal bulking response to a food

When calculating faecal bulking indices, adjustment for the relative proportions of wheat bran reference (12.5% of diet) and food being tested (50% of diet; Table 1) assumes linearity of response. To test the assumption that faecal bulking effects of breakfast cereals and wheat bran are linearly related to their inclusion level in the diet, or to the fibre dose that they provide, the bulking effects/100 g of the diets were plotted against increments in dietary fibre achieved by adding processed wheat bran fibre to the diets in the form of All Bran. The results, in Fig. 5, show that the relationship between dose of processed bran fibre in the diets and the faecal bulking response was linear, at least between about 5% and 15% All Bran fibre (about 7% and 18.7% total fibre when baseline fibre is included), the latter being the highest fibre level achievable without exceeding the maximum 50% inclusion rate of test food permitted in the faecal bulking assay. The dietary fibre content of most breakfast cereals lies

Table 3. Relative faecal bulking efficacy of breakfast cereals and their contributions of wheat bran equivalents for faecal bulk (WBE_{fb})/serving, to a daily reference value for faecal bulk (DRV_{fb} = 63 WBE_{fb})

	FBI (WBE_{fb}/100 g)	Serving size (g)	WBE_{fb}/serving (g)	DRV_{fb}/serving (%)
All Bran	51.3	45	23.10	36.7
Berry Berry Nice	8.6	30	2.59	4.1
Bran flakes	26.2	30	7.87	12.5
Chex	3.3	30	0.98	1.6
Cornflakes	–1.7	30	–0.52	–0.8
Creamoata	12.2	30	3.67	5.8
Fruitful porridge	10.5	40	4.21	6.7
Fruity Bix	13.8	40	5.51	8.7
Just right	11.7	45	5.28	8.4
Kornies	13.4	30	4.01	6.4
Miniwheats	13.0	30	3.91	6.2
Muesli	17.2	50	8.58	13.6
Multiflakes	12.6	45	5.67	9.0
Nut Feast	13.0	45	5.85	9.3
Nutrigrain	2.7	30	0.82	1.3
Oat Bran	7.7	30	2.31	3.7
Puffed rice	–0.4	30	–0.12	–0.2
Puffed wheat	8.4	30	2.51	4.0
Rolled Oats (Fleming's)	9.0	30	2.70	4.3
Rolled Oats (Pam's)	16.9	30	5.06	8.0
San Bran	81.7	45	36.78	58.3
Special K	7.5	30	2.24	3.5
Sports plus	15.1	50	7.55	12.0
Sultana bran	20.8	45	9.38	14.9
Sustain	10.6	45	4.76	7.6
Vita Brits	15.9	30	4.78	7.6
Vita crunch	4.8	60	2.87	4.5
Wheat biscuits	18.0	30	5.39	8.6
Wheat bran	100.0	63	63.00	100

DRV_{fb}, daily reference value for faecal bulk; FBI, faecal bulking index; WBE_{fb}, wheat bran equivalents for faecal bulk.

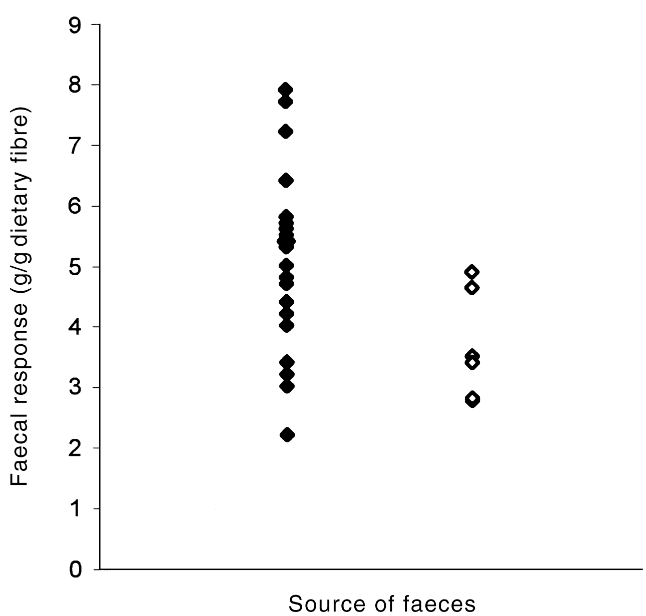

Figure 4. Weight of faeces produced by humans (◆)[7] and rehydrated faecal weight produced by the rat FBI model (◇) per gram of wheat bran dietary fibre consumed in a range of high-wheatbran foods. Each point is the mean of a trial.

within the range of dietary fibre concentrations tested in the dose–response experiment.

Precision and reproducibility of the faecal bulking assay

The precision of the measurements is of interest because the increase in fully hydrated faecal weight/100 g of diet is the basis on which FBI is calculated. As the standard deviations for the diet groups (Table 3) and standard errors of the means (Figs 2,3) show, the faecal bulking analysis can be conducted with excellent precision, considering that it is based on an *in vivo* model.

The reproducibility of the faecal bulking assay also proved to be excellent, judging from the measurements of hydrated faecal bulk for baseline and reference diets, also shown in Table 2. In three consecutive trials of different groups from the same population of rats, values of mean ± SEM for hydrated faecal mass/100 g diet intake were: 19.5 ± 0.07 g, 21.3 ± 1.6 g and 22.7 ± 0.6 g for the baseline diet; and 46.2 ± 1.7 g, 46.0 ± 1.0 g and 46.3 ± 3.5 g for the wheat bran reference diet.

Table 4. Wheat bran equivalents required in one serving of breakfast cereal, to redress shortfall in faecal bulk on the CSIRO 12345+ adult food and nutrition plan if remaining cereal component (eight servings) were wholemeal bread (Diet 1) or white bread (Diet 2)

Food category (recommended servings)		Servings	WBE_{fb}/serving†	WBE_{fb} dose Diet 1	Diet 2
Breads and cereals (9)	1 slice wholemeal bread	8	3.5	28	–
	1 slice white bread	8	0.4	–	3.2
Vegetables (4)	½ cup leafy vegetable	3	4	12	12
	½ cup orange vegetable	1	3	3	3
Fruit (3)	4–6 dried fruit	3	5	15	15
Milk products (2)		–	–	0	0
Meats (1)		–	–	0	0
Breakfast cereal to attain DRV_{fb}		1	–	5	29.8
Total (DRV_{fb})		–	–	63	63

†Based on published data.[4] DRV_{fb}, daily reference value for faecal bulk; WBE_{fb}, wheat bran equivalents for faecal bulk.

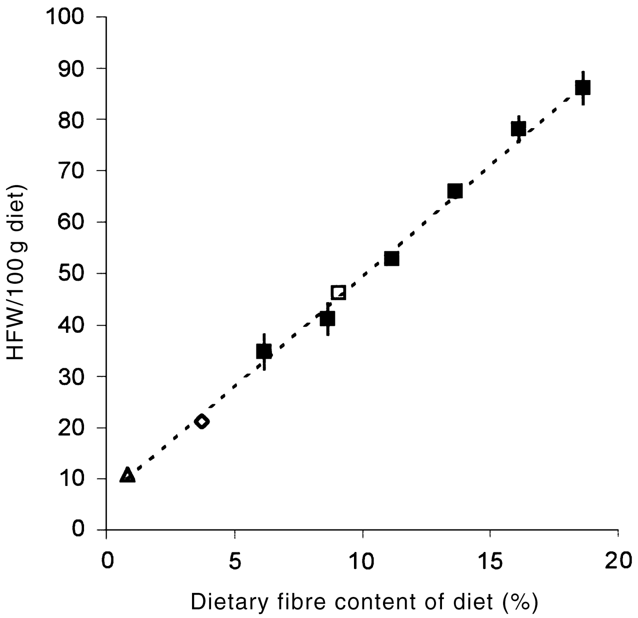

Figure 5. Hydrated faecal weight (HFW) response to dose of processed cereal dietary fibre, added in All Bran to the baseline diet to provide 2.5, 5, 7.5, 10 and 12.5% dietary fibre in addition to 3.67% baseline. (■) All Bran; (△) standard rat diet; (◇) baseline diet; (□) 12.5% wheat bran reference diet.

Discussion

Faecal increments induced by breakfast cereals

The breakfast cereals analysed were representative of the range available in local supermarkets. Most of them induced only small increases in HFW. Cereals with high levels of wheat bran were highly effective at increasing faecal bulk, and most of the others were not. 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.[9] Furthermore, wheat bran retains its efficacy as a faecal bulking agent even after extrusion cooking, which is widely used in the manufacture of cereal products, and the reduction in particle size that it causes.[10]

Contribution of dry matter and water-holding capacity to increments in faecal bulk

Increases in faecal dry matter made a larger contribution to increments in HFW than changes in FWHC, but in the case of cereals high in wheat bran, there was some increase in FWHC. The impact of wheat bran no doubt reflects the influence of its cellular structure, which provides water-retaining interstices and free space within its fermentation-resistant cell walls. In contrast, faeces derived from breakfast cereals containing little bran-like matter, and perhaps with a higher proportion of bacterial biomass, would have consisted of more tightly packed particles with less internal water retention. The two breakfast cereals that decreased FWHC were puffed rice and cornflakes, both of which are non-wheat, starch-based products that would have provided little structural residue to confer a water-holding capacity.

The lack of difference in FWHC between the different cereals, apart from in the high wheat-bran samples, also indicates that highly hydrated but fermentation-resistant polysaccharides were not present in the breakfast cereals. A number of the products would have contained digestion-resistant material, such as endosperm cell walls, pectic polysaccharides and non-lignified cell walls in fruit-based ingredients, and soluble cereal polysaccharides, such as arabinoxylans and β-glucans in oat barley and corn products. However, all such materials are either fermented or degraded in the hindgut, with the loss of their hydration properties, and do not contribute greatly to faecal bulk at the levels normally consumed.[11] None of the diets contributed material to the colon that was both resistant to fermentation and highly hydrated, such as the heteroxylan polysaccharide in psyllium husk, which has a much greater effect on FWHC[3] and has been used for centuries as a laxative.

The considerable increase in faecal water load/unit feed intake, arising from increases in faecal dry weight coupled with increases in FWHC, could provide health benefits from wash-out effects that reduce the chemical potential of reactive molecules in the colon as a result of dilution. The percentage increases in water/100 g diet measured in the experiments described may be a valid representation of the relative increases in throughput of water that would be induced by the cereal foods in the human diet, because the same factors (i.e., non-digestible fermentation-resistant food residues, bacteria and held water) are the main determinants of faecal mass and contribute to it to a similar degree in humans and in rats.[1,11]

Validity of the rat model for measuring faecal bulking efficacy

Using the rat model for measuring FBI is valid in so far as it is monogastric, is preadapted to a balanced diet containing mixed dietary fibres and, under the conditions used, fermentation is similar to that in the human colon,[11] and the same factors determine faecal bulk both in human and rehydrated rat faeces. Bulk is highly variable due to changes in water content within a human stool while rats pellet and dehydrate their faeces, but full rehydration overcomes these problems by providing a faecal mass that depends solely on the total faecal matter present and its water-holding capacity, and raises the faecal water content of the rehydrated rat pellets (mean water content = 68.1%) to within the range for human faeces (Fig. 6).[7] The rehydration step, not normally included in rat studies of faecal responses to human foods, improves the validity of the faecal bulking assay.

The results are also consistent with human data obtained from free-living subjects on mixed diets, which showed small differences in the moisture content of faeces from subjects producing less than 150 g faeces/day (69% water), compared with those producing greater than 150 g faeces/day (74% moisture).[8] The means of both the 28 rat trials and the 30 human trials (Fig. 6) showed a range of approximately only 10% in moisture content. Thus, the rehydrated rat faeces at their maximum water-holding capacity appear to satisfactorily model human faeces, rather than the colonic contents at some earlier stage of their transition to faecal matter. The linearity of the response to processed wheat fibre dose shown in Fig. 5 further attests to the robustness of the faecal bulking assay and its suitability for measuring the faecal bulking efficacy of cereal products.

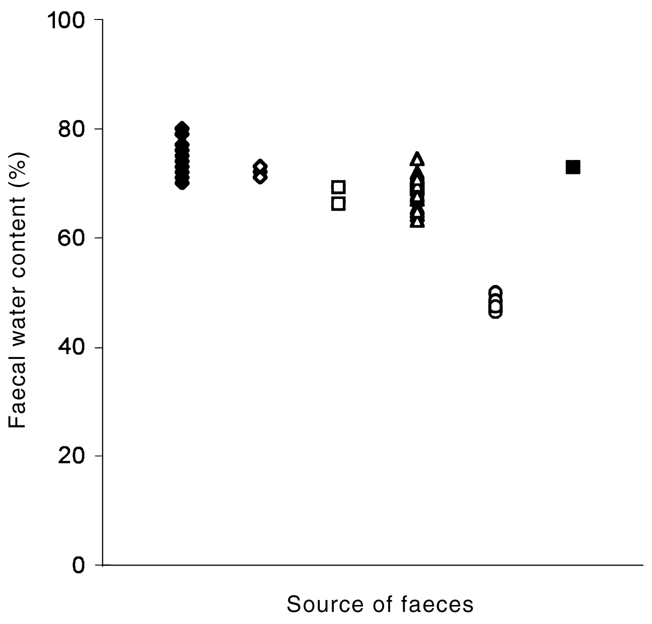

Figure 6. Water content of fresh human faeces,[7,8] and of faeces from rat faecal bulking index (FBI) model with and without rehydration. Each point is the mean of a trial. (◆) Humans, wheat bran; (◇) rats, wheat bran (reference); (□) rats, baseline; (△) rats, breakfast cereals; (○) rats, faeces not rehydrated; (■) Australians, varied diet.

The laxative effect of bulk is more likely to be due to the amount of moist bulk accumulating in the colon, rather than retention by a dehydrated faecal plug. The model applies to the contributions of colonic bulk required to maintain a theoretical steady-state system in which constipation and excessive dehydration are not already established problems. Use of the rat model overcomes the enormous logistical problems that would be encountered if humans were used for standardized comparison of a large number of samples, as in the present study.

Contribution of breakfast cereals to theoretical requirements for faecal bulk

In the adaptation of the CSIRO 12345+ food and nutrition plan, the recommended intakes of sources of dietary fibre for an average adult (in servings) are approximately nine cereals, four vegetables and three fruits/day.[12] In this plan, the WBE_{fb} content of a breakfast cereal required to ensure a total intake of 63 WBE_{fb}/day would be 5 WBE_{fb}/serving if the diet was based on wholemeal bread, and 29.8 WBE_{fb}/serving if the diet was based on white bread, as shown in Table 4. If breakfast cereals were relied on to ensure adequate daily intakes of WBE_{fb} in a diet, in which the servings of cereal were based on white flour, as an extreme, only two of the cereals would be able to redress the shortfall of 29.8 WBE_{fb} in one or two servings, namely San Bran and All Bran® (Table 3). Although based on the limited number of WBE_{fb} values currently available,[4] Table 4 suggests that if the cereal component were provided by whole grains or wholemeals, the CSIRO 12345+ adult plan would satisfy requirements for faecal bulk.

Of the 28 breakfast cereals for which faecal bulking was measured, only six provided more than 10% of the DRV_{fb}/serving (Table 3). Given that many consumers base their choices on rather broad food groups, this is a lower contribution of WBE_{fb} to faecal bulk than might be expected from a food group with a reputation for its benefits to bowel health.

Conclusion

Most Australasian breakfast cereals do not have enough faecal bulking capacity to allow them to be relied on for a large proportion of the daily requirements for faecal bulk in an average diet. Although those that are rich in wheat bran can make a substantial contribution, most cannot, and there is a need for food information that allows consumers to distinguish between the effective and the less effective breakfast cereals. Faecal bulking indices, or better still, wheat bran equivalents for faecal bulk might assist choice of foods for faecal bulk.

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