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Impact of ready-to-eat breakfast cereal (RTEBC) consumption on adequacy of micronutrient intakes and compliance with dietary recommendations in Irish adults

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Abstract

Objective: To describe the consumption of ready-to-eat-breakfast cereals (RTEBCs) in Irish adults and its impact on adequacy and safety of micronutrient intakes and compliance with dietary recommendations.
Design: Analysis for this paper used data from the North/South Ireland Food Consumption Survey that estimated habitual food intake using a 7-day food diary in a representative sample of adults aged 18–64 years ($n = 1379$; 662 men, 717 women).
Results: Despite the small quantity consumed (mean 28.6 g day^{-1} or 4.7% of total energy intake), RTEBCs made an important contribution to the mean daily intake of carbohydrate (8.1%), starch (10.8%), dietary fibre (9.8%) and non-starch polysaccharides (NSP) (10.8%) in consumers. Increased consumption was associated with a more fibre-dense diet and with greater compliance with dietary recommendations for fat, carbohydrate and NSP. Fortified RTEBCs contributed significantly to mean daily intakes of iron (18%), thiamin (14%), riboflavin (17%), niacin (15%), vitamin B_6 (13%), total folate (18%) and vitamin D (10%) and most of the contribution was from micronutrients added to RTEBCs. Increased consumption of fortified RTEBCs was associated with an increased nutrient density for a number of micronutrients and with a lower prevalence of dietary inadequacy of calcium, iron, riboflavin and folate, particularly in women. However, it was not associated with intakes in excess of the Tolerable Upper Intake Level for any micronutrient.
Conclusions: The consumption of RTEBCs is associated with improved compliance with dietary recommendations for fat, carbohydrate and fibre, with a more micronutrient-dense diet and a reduced risk of dietary inadequacy for calcium, iron, riboflavin and folate, without increasing the risk of excessive intakes of micronutrients.

Keywords
Ready-to-eat breakfast cereals
Fortification
Contribution
Macronutrient intakes
Dietary recommendations
Micronutrient adequacy

Breakfast consumption is associated with a more desirable nutrient intake in adults[1–5], adolescents and children[6–9]. In addition, nutrients omitted with breakfast are often not compensated for by other meals during the course of the day[3,4,10,11]. In a review of breakfast, Ruxton and Kirk[1] have suggested that the more desirable nutrient intake associated with breakfast consumption is due to the inclusion of ready-to-eat breakfast cereals (RTEBCs).

Breakfast cereals are generally high in carbohydrate, low in fat, some are high in fibre and many contain appreciable amounts of certain vitamins and minerals, particularly those that have been fortified. Breakfast cereals contribute significantly to the intakes of vitamins and minerals in adults[12–14] and many studies have shown that the consumption of breakfast cereals is associated with higher micronutrient intakes in adults[5,15–17], adolescents and children[7–9,18–21]. Much of the micronutrient intake from breakfast cereals can be attributed to the fortification of breakfast cereals, both in adults[13,22,23] and adolescents and children[22,24,25]. The consumption of breakfast cereals is also associated with increased milk consumption[26], which contributes to increased intakes of calcium[1,14] and vitamin A[1].

Breakfast cereals are widely consumed, particularly in Ireland[16], and a number of studies have shown an association between breakfast cereal consumption and replacement of food energy from fat with food energy from carbohydrate in adults[12,14,15,17], adolescents and children[7,10,18,20,24,25]. Intervention studies in which breakfast cereals were introduced to the diet of adults led to a reduced intake of fat and an increased intake of carbohydrate[27,28]. The consumption of breakfast cereals has also been shown to be associated with lower serum cholesterol levels in adults[29] and children[25,30].

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Some studies have shown that breakfast cereal consumption is associated with an increased fibre intake in both adults[12,14] and adolescents[24]. The consumption of breakfast cereals with higher fibre content has also been associated with an increased intake of fibre[20,31,32].

A food consumption survey in the Republic of Ireland, carried out between 1987 and 1988[33], showed that breakfast cereal made a significant contribution to the intakes of micronutrients, particularly in population groups where inadequate intakes of some micronutrients were prevalent[31]. New data on food consumption in 18–64-year-old adults is available from the North/South Ireland Food Consumption Survey, which was conducted between 1997 and 1999[34].

The aims of this paper are to describe RTEBC consumption in Irish adults, to quantify the contribution of RTEBCs to dietary intakes of macronutrients and micronutrients, and to determine their impact on adequacy and safety of micronutrient intakes and on compliance with dietary recommendations for macronutrients and fibre.

Methods

The analysis for this paper is based on data from the North/South Ireland Food Consumption Survey (NSIFCS), a cross-sectional study that was carried out between 1997 and 1999 by the Irish Universities Nutrition Alliance[34]. Individuals aged 18–64 years were randomly selected using the electoral register as the sampling frame, excluding pregnant or lactating women. Food intake was estimated in 1379 respondents (662 males and 717 females) and analysis of the demographic features in this sample has shown it to be a representative sample of the Irish adult population[35]. A more detailed account of the sampling procedure used in the NSIFCS is available elsewhere[35].

A 7-day food diary was used to collect food and beverage intake data; the methods used to quantify food and drink intakes are described in detail elsewhere[36]. The researcher made four visits to the respondent during the 7-day period: a training visit to show how the food diary was kept; a second visit 24–36 h into the recording period to review the diary, check for completeness and clarify details regarding specific food descriptors and quantities; a third visit 4 or 5 days into the recording period to check the previous 2 or 3 days and to encourage completion; and a final visit 1 or 2 days after the recording period to check the last days and to collect the diary. The respondents were asked to record detailed information regarding the types and amounts of all foods, beverages and nutritional supplements consumed over the 7-day period, the cooking method used (where applicable), the brand name of foods (where appropriate) and details of recipes and any leftovers. Data were also collected on the time of each eating or drinking occasion, the respondent's definition of each eating or drinking occasion (e.g. morning snack, lunch, etc.) and the location of the preparation or source of the meal or snack consumed (e.g. home, work, takeaway, etc.).

On the basis that different foods are best quantified using different methods and some methods of quantification are more precise than are others, a hierarchical approach to food quantification was used as follows.

1. The researcher weighed the respondent's typical portion of certain foods and beverages, particularly those that were consumed most commonly (e.g. RTEBC, home-made bread).
2. A photographic food atlas developed for the survey, which contained 60 photographs of foods consumed commonly in Ireland[37].
3. Suggested serving sizes indicated on food labels.
4. A database of average portions of certain foods (e.g. sliced meats, takeaway foods) was compiled by the research team.
5. Food weights and average food portion sizes estimated for UK adults by the Ministry of Agriculture, Fisheries and Food (MAFF)[38].
6. Household measures.
7. The researcher estimated portion sizes based on the respondent's eating patterns.

The majority of RTEBCs recorded (58%) were quantified by the researcher weighing a typical portion of breakfast cereal consumed by the respondent, 24% were quantified by assigning average food portion sizes estimated for UK adults[38], 13% were quantified from individually portioned packets and from average portion sizes suggested by the manufacturer on the label and 4% were estimated by the researcher.

Self-administered questionnaire data were also obtained on sociodemographic factors and health and lifestyle parameters.

Food intake data were analysed using WISP© (Tinuviel Software, Warrington, UK). WISP© uses data from *McCance & Widdowson's The Composition of Foods*, fifth edition[39] plus supplemental volumes[40–48] to generate nutrient intake data. Modifications were made to the food composition database: 993 extra new foods (including analysed recipes of composite dishes, nutritional supplements, generic Irish foods that were commonly consumed and new foods) were added. The data handling and processing procedures used have been described in greater detail elsewhere[36]. With regard to RTEBCs, nutrient composition data were revised for existing cereals using up-to-date manufacturers' data and new breakfast cereals were assigned new food codes with the corresponding nutrient composition data being obtained from manufacturers. The indigenous levels of micronutrients in RTEBCs (i.e. before micronutrient addition) were obtained from manufacturers' data, and the quantity of micronutrients added to RTEBCs was calculated by

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subtracting the indigenous levels in an RTEBC from the levels in the product as sold[49].

The food consumption database generated from the food survey listed each individual food item as consumed by each respondent, together with the nutrient composition for the quantity of each food consumed. Overall, 3060 different foods were recorded and this included 57 different types of RTEBC. Respondents who consumed RTEBCs at any time during the 7 days of recording were classified as RTEBC consumers. RTEBCs were classified as low-fibre if they contained less than 6 g of dietary fibre per 100 g of dry cereal and as high-fibre if they contained 6 g or more of dietary fibre per 100 g of dry cereal.

The Average Requirement (AR) was used as a cut-off point to estimate the proportion of the population subgroup with inadequate micronutrient intakes and this method has been shown to be effective in obtaining a realistic estimate of the prevalence of dietary inadequacy[50]. The AR is the daily intake value that is estimated to meet the requirement, as defined by a specified indicator of adequacy, in 50% of a life-stage or gender group[51]. The percentage of the population with a mean daily nutrient intake that is lower than the AR is taken as an estimate of the percentage of the population with inadequate intakes.

For any nutrient, estimation of the level of inadequacy by this method is most accurate if intakes and requirements are independent, if the standard deviation (SD) of intakes is at least twice as large as the SD of requirements, and if the requirements are symmetrically (but not necessarily normally) distributed. The estimate of intake should represent habitual intake and the estimate of adequacy can be influenced by underreporting of food consumption[50]. O'Brien *et al.*[52] and Hannon *et al.*[53] reported that the SDs of the mean intakes of vitamins and minerals in this population sample were greater than the commonly assumed SD of the requirement of 15% of the mean[54]. It is generally assumed that for vitamins and minerals the intakes and requirements are independent and that the average requirements for vitamins and minerals, except iron, are symmetrically distributed[52,53]. Bingham *et al.*[55] have shown that a 7-day food diary as used in this survey is a useful means of measuring habitual intake with respect to vitamins and minerals, except for retinol and carotene, where a significant contribution to mean daily intake is made by rich dietary sources that are consumed on an irregular basis. As with any dietary survey where food intake is self-reported there is evidence of misreporting; in particular, underreporting in the present survey[56]. Underreporting is likely to lead to an overestimate of the prevalence of inadequate intakes.

The risk of excessive intake of micronutrients was assessed by estimating the proportion of the population with intakes exceeding the Tolerable Upper Intake Level (UL). UL values have been established for retinol ($3000\,\mu g\,day^{-1}$)[57], vitamin D ($50\,\mu g\,day^{-1}$)[58], vitamin E ($1000\,mg\,day^{-1}$)[59], vitamin B_6 ($25\,\mu g\,day^{-1}$)[60], folic acid ($1000\,\mu g\,day^{-1}$)[61], vitamin C ($2000\,mg\,day^{-1}$)[59], calcium ($2500\,mg\,day^{-1}$)[58], phosphorus ($4000\,mg\,day^{-1}$)[58], iron ($45\,mg\,day^{-1}$)[57], copper ($10\,mg\,day^{-1}$)[57] and zinc ($40\,mg\,day^{-1}$)[57].

Data were analysed using SPSS® Version 10.0 for Windows™ (SPSS Inc., Chicago, IL, USA). The analysis was carried out both including and excluding underreporters of energy intake, identified as having a ratio of energy intake (EI) to basal metabolic rate (BMR) of less than 1.05[62]. All data presented in this paper include underreporters, as removal of underreporters did not change the overall trends observed. Tertile analysis was used to divide men and women, separately, into low, medium and high consumers of RTEBCs or fortified RTEBCs. Chi-square analysis and Pearson's chi-square were used to assess associations between sociodemographic variables and consumers and non-consumers of RTEBCs. Independent *t*-tests or the corresponding Mann–Whitney test for non-parametric data were used to assess differences between means in men and women and in RTEBC consumers and non-consumers. One-way analysis of variance with *post hoc* multiple comparisons was used to determine significant differences in means between age groups or types of RTEBC consumer. For non-parametric data, the corresponding Krusal–Wallis test was employed. Bivariate correlation analysis was used to determine the associations between nutrient intake and increased RTEBC consumption. Values of $P < 0.01$ were reported as statistically significant.

Results

RTEBC consumption

Breakfast cereals were consumed by 73% of the total sample on at least one eating occasion during the recording week. An RTEBC was consumed by 67% of the total sample (66% of men and 69% of women). Fortified RTEBCs were consumed by 60% of men and by 63% of women and on 91% of all eating occasions that included an RTEBC. Overall, 31% of men and 24% of women were consumers of low-fibre RTEBCs only, 21% of men and 27% of women were consumers of high-fibre RTEBCs only and 14% of men and 18% of women were consumers of both low- and high-fibre RTEBCs. Ninety-one per cent of all eating occasions that contained an RTEBC were consumed as part of a breakfast meal (as defined by the respondent) while 9% were consumed as part of a snack (morning, afternoon or evening snack). Ninety-six per cent of all eating occasions that included an RTEBC occurred in the respondent's home.

Table 1 compares the sociodemographic characteristics of RTEBC consumers and non-consumers, by reporting the percentage of consumers and non-consumers in each category of each characteristic listed. The consumption of RTEBCs was associated with higher educational

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Table 1 Sociodemographic characteristics of RTEBC consumers and non-consumers for men and women separately

	Men					Women				
		Non-consumers ($n = 225$)		Consumers ($n = 437$)			Non-consumers ($n = 225$)		Consumers ($n = 492$)	
	P-value*	*n*	%	*n*	%	*P*-value*	*n*	%	*n*	%
Education level										
Primary	0.004	57	25.8	83	19.5	0.000	62	28.4	87	18.0
Intermediate		56	25.3	72	16.9		58	26.6	96	19.8
Secondary		32	14.5	81	19.0		37	17.0	105	21.7
Third level		76	34.4	190	44.6		61	28.0	196	40.5
Social class†										
Managerial, professional & technical	0.001	74	34.9	194	46.9	0.054	78	37.5	225	48.2
Non-manual skilled		24	11.3	67	16.2		56	26.9	106	22.7
Manual skilled		70	33.0	85	20.5		34	16.3	72	15.4
Semi-skilled, unskilled		44	20.8	68	16.4		40	19.2	64	13.7

RTEBC – ready-to-eat breakfast cereal.
* Pearson's chi-square.
† Central Statistics Office, Ireland.

attainment (men $P = 0.004$; women $P = 0.000$); for example, a lower proportion of non-consumers compared with consumers completed secondary or third-level education (49% vs. 64% in men and 45% vs. 62% in women). In men, RTEBC consumption was associated with a higher social class status ($P = 0.001$); for example, a higher proportion of consumers (63%) compared with non-consumers (46%) were from professional, managerial, technical or non-manual households. The proportion of consumers/non-consumers of RTEBCs was independent of geographical location of inhabitancy.

The mean daily intake of RTEBCs among consumers was 28.6 g, and men (31.1 g) consumed significantly higher quantities ($P < 0.01$) than women (26.5 g) (Table 2). While the percentage of consumers of RTEBCs was lower in 51–64-year-olds than in 18–50-year-olds, the percentage of consumers of other breakfast cereals (e.g. porridge) was higher in this age group (data not shown). At the 95th percentile of mean daily intake (72.1 g), RTEBC consumption was less than 2 average portions among consumers, which indicates that RTEBCs were not consumed in very large quantities by the vast majority of adults.

Table 2 Mean daily intake of RTEBC (consumers only) by sex and age group

				RTEBC intake (g day^{-1})				
						Percentile		
	Age (years)	*n*	% Consumers	Mean	SD	5	50	95
All	18–64	929	67.4	28.6	23	4.3	23.6	72.1
Men	18–64	437	66.0	31.1	25	4.3	25.7	77.1
	18–35	173	68.4	32.4	27	4.3	25.0	88.2
	36–50	166	70.3	30.3	24	4.3	26.1	72.8
	51–64	98	56.6	30.0	25	4.3	25.7	77.3
Women	18–64	492	68.6	26.5	21	4.3	21.4	65.9
	18–35	189	70.3	24.5	19	4.3	20.0	63.0
	36–50	204	71.3	26.4	21	4.3	22.9	65.8
	51–64	99	61.1	30.3	25	4.3	23.6	91.0

RTEBC – ready-to-eat breakfast cereal; SD – standard deviation.

The mean portion size of RTEBCs consumed per eating occasion in consumers was 44.9 g and this was higher in men (48.6 g) than in women (41.7 g). A number of methods were used to quantify the intake of RTEBCs, and the mean portion size varied depending on the method used. The mean intake of RTEBCs per eating occasion was 51.8 g (55.6 g in men and 48.7 g in women) using the weighed method, 38.9 g (41.2 g in men and 36.1 g in women) using MAFF portion sizes, 38.3 g (44.4 g in men and 31.1 g in women) using weights from individually portioned packets or from labelled typical portion size, and 41.6 g (45.2 g in men and 39.6 g in women) using estimated portion size. The mean portion size was therefore higher when the weighed method was used (represented 58% of all RTEBC eating occasions recorded), compared with other methods of quantification, and this suggests that other methods of quantification may underestimate RTEBC intake.

The mean frequency of RTEBC consumption among consumers only, over the 7-day recording period, was 4.3 times in men and women. In women the mean frequency of consumption increased from 4.1 in 18–35-year-olds to 4.5 in 51–64-year-olds, while in men the frequency of consumption was similar across all age groups. During the 7 days of recording, 37% of RTEBC consumers consumed an RTEBC on 6 or more eating occasions, 24% consumed an RTEBC on 4 to 5 eating occasions and 39% consumed an RTEBC on 1 to 3 eating occasions.

The impact of RTEBCs on macronutrient intakes

Table 3 shows the percentage contribution of RTEBCs to the mean daily intake of macronutrients in men and women

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Table 3 Percentage contribution of RTEBCs to mean daily intakes of macronutrients and dietary fibre (consumers only)

	% Contribution			
	Men ($n = 437$)		Women ($n = 492$)	
	Mean	SD	Mean	SD
Total energy	4.2	3	5.2	4
Protein	2.8	2	3.6	3
Total fat	0.9	1	1.2	2
Carbohydrate	7.5	5	8.7	6
Total sugar	3.9	5	5.1	5
Starch	10.0	7	11.5	8
Dietary fibre	8.3	8	11.2	11
NSP	8.7	10	12.6	13

RTEBC – ready-to-eat breakfast cereal; SD – standard deviation; NSP – non-starch polysaccharides.

who were RTEBC consumers. RTEBCs contributed 4.7% of total energy intake and, relative to energy, contributed greater proportions of dietary carbohydrate (8.1%), starch (10.8%), dietary fibre (9.8%) and non-starch polysaccharides (NSP) (10.8%) and smaller proportions of protein (3.2%), total sugar (4.5%) and total fat (1.1%) in men and women overall. The percentage contribution of RTEBCs to macronutrient and fibre intakes was similar across all age groups in men and women. RTEBCs made a significantly higher ($P < 0.01$) contribution to the diet of women than men for all macronutrients and fibre.

When expressed as percentage of food energy, mean daily intake of carbohydrate was significantly higher and mean daily intake of total fat was significantly lower in RTEBC consumers compared with non-consumers. Increased RTEBC consumption was associated with an increase in carbohydrate intake and a decrease in fat intake in men and women (Table 4). RTEBC consumers had a significantly higher mean daily intake of sugar as a percentage of food energy and increased RTEBC consumption was associated with increased sugar intake in women, but not in men. Increased RTEBC consumption was also associated with an increased starch intake in men only.

Among RTEBC consumers there was a higher dietary fibre intake (per 10 MJ) in men and women and a higher NSP intake (per 10 MJ) in women only, compared with non-consumers. Increased RTEBC consumption was associated with increased dietary fibre and NSP intakes in both men and women (Table 3). RTEBC consumers who consumed high-fibre RTEBCs only had a significantly ($P < 0.001$) more fibre-dense diet than consumers of low-fibre RTEBCs only or consumers of both high- and low-fibre RTEBCs (data not shown).

Increased RTEBC consumption was associated with an increase in the proportion of individuals meeting the recommendations by the Committee on Medical Aspects of Food Policy[63] for 50% or more of food energy from carbohydrate, 35% or less of food energy from fat and 18 g of NSP (Table 5). In relation to carbohydrate and fat, the effect of RTEBC consumption was more pronounced in women (e.g. achievement of the carbohydrate and fat recommendations increased from 14% and 18%, respectively, in women who were non-consumers to 43% and 55%, respectively, in high consumers). In men the proportion of individuals with NSP intakes of 18 g or more increased from 28% in non-RTEBC consumers to 60% in high consumers while in women these proportions were 5% in non-consumers and 35% in high consumers. Fifty-seven per cent of men and 28% of women consumers of high-fibre RTEBCs had NSP intakes of 18 g or more, compared with 26% of men and 9% of women consumers of low-fibre RTEBCs (data not shown).

Table 4 Mean daily intakes of macronutrients (as a percentage of food energy excluding ethanol) and fibre (per 10 MJ of food energy excluding ethanol) in non-consumers and consumers of RTEBCs and the correlation coefficient (r) of macronutrient intake with consumption of RTEBCs in consumers

	Men					Women					Correlation coefficient			
	Non-consumers ($n = 225$)		Consumers ($n = 437$)			Non-consumers ($n = 225$)		Consumers ($n = 492$)			Men ($n = 437$)		Women ($n = 492$)	
Nutrient	Mean	SD	Mean	SD	*P*-value	Mean	SD	Mean	SD	*P*-value	*r*	*P*-value	*r*	*P*-value
Protein (% food energy)	17.0	3	16.6	3	0.097	16.2	3	16.2	3	0.933	−0.160	**0.001**	−0.011	0.811
Fat (% food energy)	38.1	6	36.6	5	**0.000**	39.1	6	36.2	6	**0.000**	−0.159	**0.001**	−0.210	**0.000**
Carbohydrate (% food energy)	45.0	5	46.8	5	**0.000**	44.8	5	47.4	6	**0.000**	0.225	**0.000**	0.194	**0.000**
Sugar (% food energy)	16.3	5	17.6	5	**0.002**	16.8	5	18.6	5	**0.000**	0.085	0.092	0.165	**0.000**
Starch (% food energy)	30.4	6	31.0	5	0.200	29.4	5	30.4	5	0.028	0.149	**0.002**	0.027	0.553
Dietary fibre (g/10 MJ)	23.2	7	24.4	7	**0.007**	23.7	6	26.9	8	**0.000**	0.207	**0.000**	0.207	**0.000**
NSP (g/10 MJ)	16.3	6	17.0	6	0.034	16.3	5	19.3	7	**0.000**	0.231	**0.000**	0.247	**0.000**

RTEBC – ready-to-eat breakfast cereal; SD – standard deviation; NSP – non-starch polysaccharides.
The *t*-test and the equivalent Mann–Whitney test (for non-parametric data) were used to compare means between RTEBC consumers and non-consumers. Bivariate correlation analysis was used to measure the association between mean intake of macronutrients and RTEBC consumption in consumers only.

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Table 5 Percentage achieving dietary recommendations for macronutrients in consumers of RTEBCs, by tertile of consumption and in non-consumers

	% Achieving dietary recommendation							
	Men				Women			
Consumption category*	Non ($n = 225$)	Low ($n = 146$)	Medium ($n = 147$)	High ($n = 144$)	Non ($n = 225$)	Low ($n = 162$)	Medium ($n = 170$)	High ($n = 160$)
Recommendation†								
% Food energy from CHO ≥ 50%	17	16	29	33	14	23	30	43
% Food energy from fat ≤35%	25	29	37	39	18	31	32	55
NSP ≥ 18 g day^{-1}	28	27	33	60	5	13	14	35

RTEBC – ready-to-eat breakfast cereal; CHO – carbohydrate; NSP – non-starch polysaccharides.
* Men: low consumers, ≤16.4 g day^{-1}; medium consumers, >16.4–35.7 g day^{-1}; high consumers, >35.7 g day^{-1}. Women: low consumers, ≤14.3 g day^{-1}; medium consumers, >14.3–30.0 g day^{-1}; high consumers, >30.0 g day^{-1}.
† Department of Health, 1991[63].

The impact of fortified RTEBCs on micronutrient intakes

Of the 57 different RTEBCs that were recorded, 44 (77%) were fortified to varying levels with between four and 10 micronutrients. The micronutrients (number of cereals fortified) that were added to RTEBCs included: calcium (one), iron (43), zinc (two), vitamin D (20), vitamin E (five), thiamin (44), riboflavin (44), niacin (36), vitamin B_6 (37), vitamin B_{12} (38), folic acid (36), biotin (one), pantothenic acid (five) and vitamin C (eight).

Table 6 shows the percentage contribution of fortified RTEBCs to the mean daily micronutrient intake (from all sources) and the corresponding contribution of added nutrients to mean daily micronutrient intake among consumers of fortified RTEBCs. Fortified RTEBCs contributed 10% or more to the micronutrient intake of fortified RTEBC consumers for the following nutrients: iron (18.2%), thiamin (14.3%), riboflavin (16.5%), niacin (15.4%), vitamin B_6 (13.0%), total folate (17.7%) and vitamin D (10.2%) in men and women overall. The contribution of fortified RTEBCs to the mean daily intake of micronutrients was significantly higher ($P < 0.01$) in women than in men, except for calcium, and was similar across the different age groups of men and women. Micronutrients added to RTEBCs made an important contribution to the mean daily intake of iron (13.7%), thiamin (13.0%), riboflavin (15.2%), niacin (10.5%), vitamin B_6 (12.3%), folic acid (15.0%) and vitamin D (10.2%) in the population, with a higher contribution to intakes in women than men. All of the vitamin D and most of the thiamin (86%), riboflavin (90%), vitamin B_6 (89%), vitamin B_{12} (97%), niacin (63%), folic acid (75%), vitamin C (73%) and iron (66%) in fortified RTEBCs were derived from added micronutrients.

Table 6 Percentage contribution of fortified RTEBCs and contribution of micronutrients added to RTEBCs to mean daily micronutrient intake (from all sources) in fortified RTEBC consumers

	% Contribution							
	Men ($n = 397$)				Women ($n = 450$)			
	Fortified RTEBCs		Added micronutrient		Fortified RTEBCs		Added micronutrient	
Nutrient	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Calcium	0.9	2	0.2	1.6	1.5	3	0.5	2.1
Magnesium	4.5	5	0	0	7.0	7	0	0
Phosphorus	2.8	4	0	0	4.5	5	0	0
Iron	15.4	11	11.7	9.5	20.7	16	15.5	14.0
Copper	3.7	5	0	0	4.9	6	0	0
Zinc	2.9	4	0.1	1.1	5.2	6	0.4	3.0
Vitamin A	0.0	0	0	0	1.5	15	0	0
Vitamin D	5.9	13	5.9	13.0	12.9	19	12.9	19.0
Vitamin E	3.0	7	1.8	6.7	5.4	10	4.2	10.4
Thiamin	13.1	9	12.0	8.5	15.5	11	14.0	11.0
Riboflavin	15.4	10	14.3	9.4	17.5	12	15.9	10.7
Niacin	13.7	10	10.2	8.6	16.9	12	10.7	10.2
Vitamin B_6	10.8	9	10.2	9.5	14.9	13	14.2	12.6
Vitamin B_{12}	4.0	4	4.0	4.5	6.2	6	6.2	6.5
Folate	16.3	13	14.0	12.4	18.9	15	15.8	13.9
Pantothenic acid	1.9	3	0.6	2.8	3.6	6	1.4	5.2
Biotin	2.3	4	0.0	0.0	3.8	6	0.0	0.0
Vitamin C	0.9	4	0.9	3.7	3.2	8	3.2	8.3

RTEBC – ready-to-eat breakfast cereal; SD – standard deviation.

Among RTEBC consumers, a significant proportion of the Population Reference Intake (PRI)[54] was obtained from added micronutrients, particularly for iron (18.6%), thiamin (29.7%), riboflavin (22.3%), niacin (17.9%), vitamin B_6 (30.7%), vitamin B_{12} (14.5%) and total folate (24.8%) in men and women (Table 7). The percentage contribution of added nutrients to the PRI was significantly higher ($P < 0.01$) in men than women for iron, and significantly higher ($P < 0.01$) in women than men for calcium, thiamin, vitamin B_6 and vitamin C. There was a significant increase ($P < 0.001$) in the percentage contribution of added nutrients to the PRI with increased consumption of fortified RTEBCs, except for calcium and zinc in men and women and for vitamin C in men.

When compared with non-consumers, fortified RTEBC consumers had significantly higher intakes (per 10 MJ) of iron, thiamin, riboflavin and total folate in men and women, calcium in men only, and phosphorus, niacin, vitamin B_6, pantothenic acid, vitamin C and vitamin D in women (Table 8). Increased fortified RTEBC consumption was associated with an increased intake (per 10 MJ) of iron,

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Table 7 Percentage of the PRI* obtained from micronutrients added to RTEBCs in fortified RTEBC consumers, by tertile of RTEBC consumption in men and women

Consumption category†	PRI		% of PRI															
			Men								Women							
			Low ($n = 132$)		Medium ($n = 133$)		High ($n = 132$)		Total ($n = 397$)		Low ($n = 143$)		Medium ($n = 155$)		High ($n = 152$)		Total ($n = 450$)	
	Men	Women	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nutrient																		
Calcium	700 mg	700 mg	0.0	0	0.1	1	0.6	3	0.3	2	0.1	0	0.5	2	1.5	6	0.7	3
Iron	9 mg	16 mg‡, 8 mg§	6.2	4	17.7	10	39.8	36	21.2	26	3.8	3	11.7	11	32.9	33	16.4	24
Zinc	9.5 mg	7 mg	0.0	0	0.3	3	0.0	0	0.1	1	0.0	0	0.3	3	1.3	7	0.6	5
Thiamin	100 μg/MJ	100 μg/MJ	8.5	5	24.6	13	43.4	23	25.5	21	10.3	6	28.8	18	59.8	37	33.4	32
Riboflavin	1.6 mg	1.3 mg	6.2	3	17.4	5	40.7	17	21.4	18	6.8	3	18.9	7	42.5	23	23.0	20
Niacin	1.6 mg/MJ	1.6 mg/MJ	5.8	4	16.5	10	27.6	18	16.6	15	6.7	5	16.8	15	33.1	28	19.1	22
Vitamin B_6	15 μg/g protein	15 μg/g protein	8.2	6	24.6	16	40.7	34	24.5	26	10.6	8	28.9	22	67.6	45	36.1	38
Vitamin B_{12}	1.4 μg	1.4 μg	4.3	3	11.7	7	25.4	24	13.8	17	3.9	3	10.9	8	30.0	21	15.1	17
Folate	200 μg	200 μg	8.2	6	24.3	14	48.1	43	26.9	31	7.1	5	16.8	12	44.3	31	23.0	25
Vitamin C	45 mg	45 mg	0.7	3	2.2	8	4.5	16	2.4	11	1.7	4	4.3	10	13.9	29	6.7	19

PRI – Population Reference Intake; RTEBC – ready-to-eat breakfast cereal; SD – standard deviation.
* Reports of the Scientific Committee for Food, 1993[54].
† Men: low consumers, ≤ 16·4 g day^{-1}; medium consumers, > 16·4–35·7 g day^{-1}; high consumers, > 35·7 g day^{-1}. Women: low consumers, ≤ 14·3 g day^{-1}; medium consumers, > 14·3–30·0 g day^{-1}; high consumers, > 30·0 g day^{-1}.
‡ PRI to cover 90% of women.
§ PRI to cover postmenopausal women.

thiamin, riboflavin, vitamin B_6 and total folate in men and women and of calcium, vitamin D, niacin and vitamin B_{12} in women. These trends remained the same when the contribution of nutritional supplements was excluded (data not shown).

Consumption of RTEBCs was associated with a lower prevalence of inadequate intake of a number of nutrients, particularly of calcium, copper, zinc, riboflavin and vitamin C in men and women and iron and total folate in women (Table 9). As fortified RTEBC consumption increased from non-consumption to high consumption there was a reduction in the prevalence of inadequate intake of calcium, iron, zinc, riboflavin, total folate and vitamin C.

Table 10 shows the effect of micronutrient addition to RTEBC on the prevalence of inadequacy of micronutrient intakes, expressed as a percentage with intakes below the AR[54], in fortified RTEBC consumers. In consumers, the added nutrients reduced the proportion of individuals with inadequate intakes of riboflavin in men and women and of iron and total folate in women.

No fortified RTEBC consumers had micronutrient intakes exceeding the UL for any micronutrient, except for retinol (2.0% of individuals exceeded the UL of 3000 μg[57]), iron (1.9% exceeded the UL of 45 mg[57]) and vitamin B_6 (1.2% exceeded the UL of 25 mg[60]). Retinol was not added to RTEBCs and the proportion exceeding the UL for iron and vitamin B_6 remained unchanged when the contribution of the added micronutrients was excluded from the intake estimate (data not shown).

The effect of underreporting

The potential impact of underreporting of food consumption was examined. The proportion of individuals with implausibly low energy intakes (EI/BMR < 1.05[62]) was 20% of the total sample and this percentage was higher in non-consumers (20% in men and 29% in women) than in consumers of RTEBC (13% in men, 22% in women). However, chi-square analysis showed that EI/BMR < 1.05 or > 1.05 was independent of consumption (or non-consumption) of RTEBCs in men and women. In women, the mean EI/BMR was higher ($P < 0.01$) in RTEBC consumers (1.25) than in non-consumers (1.34). When EI/BMR was correlated with the level of RTEBC consumption, a positive association was observed between increasing EI/BMR and increasing RTEBC consumption, in men ($r = 0.268$, $P < 0.01$) and in women ($r = 0.118$, $P < 0.001$). Removal of 'underreporters' from the analysis did not affect the trends observed in the association of RTEBC consumption with intake or adequacy of micronutrients, intakes of macronutrients and fibre, or compliance with dietary recommendations.

Discussion

The current paper evaluated the consumption of RTEBCs with regard to the nutrient quality of the diet, compliance with recommendations for macronutrients and fibre, and adequacy of intake of micronutrients. The results indicate that, despite being consumed in relatively small quantities, RTEBCs were associated with a replacement of food energy from fat with food energy from carbohydrate and a more fibre-dense diet. This in turn was associated with greater compliance with dietary recommendations for fat, carbohydrate and fibre among consumers, which is in line with key targets for health promotion. Fortified RTEBCs have a high nutritive value and made an important

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Table 8 Mean daily intakes of micronutrients (per 10 MJ of food energy excluding ethanol energy) in fortified RTEBC consumers and non-consumers by sex and the correlation coefficient (r) of total micronutrient intake (per 10 MJ) with increased consumption of fortified RTEBCs in consumers only

	Men					Women					Correlation coefficient			
	Non-consumers ($n = 265$)		Consumers (n = 397)		Test for significant difference	Non-consumers ($n = 267$)		Consumers ($n = 450$)		Test for significant difference	Men ($n = 397$)		Women ($n = 450$)	
Nutrient per 10 MJ	Mean	SD	Mean	SD	*P*-value	Mean	SD	Mean	SD	*P*-value	*r*	*P*-value	*r*	*P*-value
Calcium (mg)	871	239	944	235	**0.000**	977	459	1032	280	0.074	0.046	0.358	0.181	**0.000**
Magnesium (mg)	351	99	346	108	0.058	341	94	356	90	0.033	−0.025	0.615	0.069	0.145
Phosphorus (mg)	1608	287	1602	282	0.795	1535	295	1623	293	**0.000**	−0.063	0.209	0.108	0.021
Iron (mg)	13.4	4	14.7	5	**0.000**	16.9	23	21.0	27	**0.000**	0.304	0.000	0.384	**0.000**
Copper (mg)	1.49	0.8	1.50	0.7	0.545	1.68	1.0	1.63	0.8	0.293	−0.003	0.945	−0.021	0.650
Zinc (mg)	11.5	4	11.1	4	0.083	11.8	7	11.5	5	0.169	0.037	0.459	0.079	0.093
Total vitamin A (μg)	1028	982	996	859	0.631	1283	1168	1252	986	0.956	−0.079	0.118	−0.068	0.152
Vitamin D (μg)	3.81	4.1	3.54	3.1	0.690	4.68	6.5	4.78	4.7	**0.001**	0.005	0.925	0.164	**0.000**
Vitamin E (μg)	11.1	35	11.5	45	0.271	13.8	29	14.9	36	0.622	−0.043	0.396	0.045	0.346
Thiamin (mg)	2.20	2.1	2.32	1.4	**0.000**	2.67	4.3	3.01	5.4	**0.000**	0.293	0.000	0.293	**0.000**
Riboflavin (mg)	1.90	0.8	2.30	1.4	**0.000**	2.56	4.3	2.82	3.7	**0.000**	0.379	0.000	0.440	**0.000**
Niacin (mg)	27.6	11	28.6	10	0.074	26.5	12	30.0	13	**0.000**	0.070	0.164	0.263	**0.000**
Vitamin B_6 (mg)	3.43	2.1	3.42	1.8	0.295	4.02	7.3	4.88	9.9	**0.000**	0.152	0.002	0.302	**0.000**
Vitamin B_{12} (μg)	5.32	4.1	5.40	3.7	0.101	5.54	5.1	5.63	4.5	0.065	0.008	0.868	0.160	**0.001**
Folate (μg)	316	136	340	118	**0.000**	308	155	391	213	**0.000**	0.247	0.000	0.334	**0.000**
Pantothenic acid (mg)	6.37	2.4	6.43	3	0.957	7.22	6.4	7.28	6	**0.007**	0.036	0.477	0.085	0.073
Biotin (μg)	42.2	20	42.1	24	0.202	48.2	41	46.3	31	0.768	−0.056	0.266	−0.013	0.789
Vitamin C (mg)	111	226	126	308	0.099	151	257	154	258	**0.000**	0.098	0.051	0.027	0.567

RTEBC – ready-to-eat breakfast cereal; SD – standard deviation.
The *t*-test and the equivalent Mann–Whitney test (for non-parametric data) were used to compare means between fortified RTEBC consumers and non-consumers.
Bivariate correlation analysis was used to measure the association between mean intake of macronutrients and fortified RTEBC consumption in consumers only.

Table 9 Percentage of men and women with inadequate* intakes of micronutrients in non-consumers and fortified RTEBC consumers, by tertile of fortified RTEBC consumption

			% With inadequate intake							
			Men				Women			
	AR‡									
Consumption category†	Men	Women	Non ($n = 265$)	Low ($n = 132$)	Medium ($n = 133$)	High ($n = 132$)	Non ($n = 267$)	Low ($n = 143$)	Medium ($n = 155$)	High ($n = 152$)
Nutrient										
Calcium	550 mg	550 mg	15	9	10	3	33	20	21	10
Iron	7 mg	10 mg (18–50 years), 6 mg (51–64 years)	5	2	0	0	55	47	31	12
Copper	0.8 mg	0.8 mg	9	11	8	3	27	19	30	14
Zinc	7.5 mg	5.5 mg	14	17	17	5	22	13	17	5
Vitamin A	500 μg	400 μg	24	24	16	13	21	10	15	16
Riboflavin	1.3 mg	1.1 mg	21	14	5	2	38	20	11	0
Folate	140 μg	140 μg	5	2	1	0	19	5	4	1
Vitamin C	30 mg	30 mg	9	11	8	2	15	7	5	4

RTEBC – ready-to-eat breakfast cereal; AR – Average Requirement.
* Inadequate intake is defined as the percentage of individuals with a mean daily micronutrient intake below the AR.
† Men: low consumers, $\leq 14.2\,g\,day^{-1}$; medium consumers, $>14.2–31.0\,g\,day^{-1}$; high consumers, $>31.0\,g\,day^{-1}$. Women: low consumers, $\leq 12.9\,g\,day^{-1}$; medium consumers, $>12.9–28.6\,g\,day^{-1}$; high consumers, $>28.6\,g\,day^{-1}$.
‡ Report of the Scientific Committee for Food, 1993[54].

Table 10 The effect of micronutrient addition to RTEBCs on the prevalence of inadequacy of micronutrient intake (expressed as % with intake < AR*) in fortified RTEBC consumers

		% With inadequate intake			
		Men ($n = 397$)		Women ($n = 450$)	
Nutrient	% of fortified RTEBCs fortified with nutrient	Not added	Added	Not added	Added
Calcium	2	8	7	17	17
Iron	98	5	1	50	30
Zinc	5	13	13	12	12
Riboflavin	100	15	7	24	10
Folate	82	4	1	12	3
Vitamin C	18	7	7	6	5

RTEBC – ready-to-eat breakfast cereal; AR – Average Requirement.
* Report of the Scientific Committee for Food, 1993[54].

contribution to vitamin and mineral intakes in the diets of consumers. In addition, consumption was associated with lower levels of inadequacy of micronutrient intakes. The benefits for micronutrients were largely due to the fortification of RTEBCs. RTEBC consumption appears to be an important indicator of a diet that is a more fibre- and micronutrient-dense and more balanced in terms of macronutrients. The consumption of RTEBCs was also associated with a higher level of educational attainment in men and women and with a higher social class status in men, which indicates that those who receive less education or have a lower social class status are less likely to consume RTEBCs.

Although RTEBCs were consumed in relatively small quantities (an average of 28.6 g day^{-1}) and provided only 4.7% of the total daily energy intake among consumers, relative to energy they made a higher contribution to the mean daily intake of carbohydrate (8.1%), starch (10.8%) and NSP (10.8%) and a lower contribution to sugar (4.5%) and total fat (1.1%). On average the amount of sugar added to food at a breakfast that contained an RTEBC was slightly higher (0.7 g) than at a breakfast that did not contain an RTEBC. Previous analysis of these survey data has shown that the percentage of Irish adults who did not meet the dietary recommendations[63] for fat (66%) and carbohydrate (75%) was high[64]. This study shows that RTEBC consumption was associated with lower food energy from fat and higher food energy from carbohydrate and increased consumption of RTEBC was associated with a higher proportion of individuals achieving the dietary recommendations for fat and carbohydrate. For example, in women who were high consumers of RTEBCs, the proportion achieving 35% or less of food energy from fat was 55%, compared with 18% in low consumers, while the proportion with intakes of 50% or more of food energy from carbohydrate was 43%, compared with 14% in low consumers.

Other studies have demonstrated an association between increased breakfast cereal consumption and replacement of energy from fat with energy from carbohydrate[12,14,17,25]. Intervention studies involving the daily consumption of breakfast cereals have reported a 5–6% (unit percentage) decrease in food energy from fat with a corresponding 5–6% increase in energy from carbohydrate among college students[28] and Finnish adults[27], and a 2.5% reduction in energy from saturated fat[27]. The lower fat intake associated with breakfast cereal consumption may explain the association of breakfast cereal consumption with reduced serum cholesterol levels in adults[27].

Previous analysis of the North/South Ireland Food Consumption data[65] showed that a high proportion (77%) of this adult population had mean daily intake below the recommended intake of 18 g of NSP[63]. The current analysis has shown that RTEBC consumption was associated with a higher likelihood of achieving the recommendation for NSP. For example, the proportion with NSP intake of 18 g or more was substantially higher in high consumers than in non-consumers of RTEBCs (60% vs. 28% in men and 35% vs. 5% in women). While this is partly due to the increased energy intake that is associated with higher RTEBC consumption, the fibre density of the diet also increased with increased RTEBC consumption. The consumption of high-fibre RTEBC was associated with a more fibre-dense diet compared with the consumption of low-fibre RTEBC or a mixture of low- and high-fibre RTEBCs. Emmett *et al.*[32] showed that British adults who consumed higher amounts of NSP from breakfast cereals were more likely to meet the recommended target of 18 g of NSP. Other studies have also demonstrated a higher fibre intake among breakfast cereal consumers[12,14,17].

The overall improved balance of fat and carbohydrate and the higher intake of fibre that is associated with RTEBC consumption may partly be explained by the dietary contribution of the RTEBCs consumed. RTEBCs are generally high in carbohydrate, low in fat and can be high in fibre. However, it may also be influenced by displacement of other foods or by different food choices made by RTEBC consumers in the overall diet.

Impact of fortified RTEBCs on vitamin and mineral intakes

Despite the relatively small quantity consumed, fortified RTEBCs made an important contribution to the intakes of

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micronutrients. This contribution was most significant (15–18%) for iron, riboflavin, niacin and total folate, to a lesser extent (10–14%) for thiamin, vitamin B_6 and vitamin D, with the majority of the contribution attributable to added micronutrients. Added micronutrients also made an important contribution to the PRI (14–31%) for a number of nutrients (i.e. iron, thiamin, riboflavin, niacin, vitamin B_6, vitamin B_{12} and total folate), and this contribution ranged from 25 to 68% among high consumers of RTEBCs for certain nutrients (e.g. iron, thiamin, riboflavin, niacin, vitamin B_6, vitamin B_{12} and total folate). Other studies have also shown that RTEBCs made an important contribution to the daily intakes of selected fortified vitamins and minerals[12,15]. A previous Irish survey[33] showed that breakfast cereals (all types) provided 16% of vitamin B_6, 17% of total folate, 23% of vitamin D and 14% of iron from food sources in children and adults. Subar *et al.*[13] showed that RTEBCs were among the top 10 food sources for 15 of 18 micronutrients examined in US adults and this was primarily due to the fortification of these cereals.

Increased consumption of fortified RTEBCs was associated with a lower prevalence of inadequate intake of calcium, copper, zinc, riboflavin and vitamin C in both men and women and of iron and total folate in women. For some micronutrients this is at least partly related to the addition of micronutrients to RTEBCs (e.g. riboflavin in men and women, and iron and folate in women). For other nutrients (e.g. calcium, copper, zinc and vitamin C), this is due to increased intakes from other foods as these nutrients are either not added to RTEBCs or added to only few products. In the case of calcium, the higher intakes and the lower prevalence of inadequacy of calcium intakes associated with increased RTEBC consumption appear largely to be due to the addition of milk to cereals, as it has been estimated that, on average, an additional 98 g of milk was consumed at a breakfast that contained an RTEBC compared with a breakfast that did not[66]. Previous studies have demonstrated the positive impact of fortified breakfast cereals on micronutrient intakes in the diet of adults[3] and children[24,25]. Furthermore, some studies have shown that RTEBC consumers had a higher status for thiamin, riboflavin, folate and β-carotene compared with non-consumers of RTEBCs[15]. Consumption of RTEBCs fortified with folic acid is associated with higher serum folate concentrations[67] and lower serum homocysteine concentrations[68,69].

Among RTEBC consumers, the UL was not exceeded for any fortified micronutrient except iron (1.9% of subjects) and vitamin B_6 (1.2% of subjects). Intake in excess of the UL for iron and vitamin B_6 was not associated with the addition of these micronutrients to RTEBCs since the proportion of individuals with intakes exceeding the UL for these micronutrients remained unchanged when the added micronutrients were excluded from the intake estimate. Kiely *et al.*[70] have shown that all of the individuals in this study population who exceeded the UL for iron and vitamin B_6 were consumers of nutritional supplements.

Conclusion

Despite being consumed in small quantities, RTEBC consumption was associated with greater compliance with dietary recommendations for fat, carbohydrate and fibre, which is in line with the key targets for health promotion. The consumption of RTEBCs is also associated with a more micronutrient-dense diet and a reduced risk of dietary inadequacy of calcium, iron, riboflavin and folate, particularly in women. Fortified RTEBC consumption was not associated with increased risk of excess for any micronutrient. Further research is needed to determine the extent to which the benefits of consuming RTEBCs are due to the nutritional contribution of the breakfast cereal and the milk consumed with it or the association of RTEBC consumption with healthier food choices in the overall diet.

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