The impact of voluntary fortification of foods on micronutrient intakes in Irish adults

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The objective of this work was to quantify the impact of the voluntary fortification of foods on dietary intakes of vitamins and minerals of Irish adults. Foods that were voluntarily fortified were identified and pre- and post-fortification levels of micronutrients were determined from data supplied by manufacturers and food composition tables. Using food consumption data in 1379 adults aged 18–64 years, estimated using a 7-d food diary during the North/South Ireland Food Consumption Survey, intakes of micronutrients were determined, both including and excluding the fortification component in foods. Of approximately 3000 foods recorded as consumed, 1·9 % were fortified, mainly breakfast cereals and beverages. Median micronutrient content of fortified foods (FF) ranged from 18–33 % EC RDA per typical serving. Among consumers (65 % of men, 68 % of women), FF contributed, on average, 3·9 % (men) and 5·0 % (women) to mean daily intake (MDI) of energy. Relative to their contribution to MDI of energy, FF contribute a greater % MDI for Fe (men 16, women 19), folate (men 18, women 21), vitamins B_1 (men 14, women 16), B_2 (men 16, women 18), B_6 (men 12, women 15), D (men 5, women 11), B_{12} (men 5, women 7) and niacin (men 10, women 12). Fortification significantly improved the adequacy of intake of some micronutrients, particularly of riboflavin, folate, vitamin D and Fe in women and did not contribute to an increased risk of adverse effects from excessive intake of any micronutrient.

Voluntary fortification: Micronutrient intakes: Adults, Adequacy: Excess

Studies in Ireland (Hannon *et al.* 2001; O'Brien *et al.* 2001) and in other European countries (Scientific Co-operation Task 7.1.1 Working Group, 1997; Brussard *et al.* 1998) have indicated a significant prevalence of inadequate intakes or poor nutritional status for some micronutrients in several population subgroups.

The voluntary addition of vitamins and minerals to foods is one way that micronutrient intakes can be increased and the risk of inadequate intakes can be reduced. The practice of such addition varies widely among EU countries, partly due to varied regulatory environments in the member states. The EC has published a proposal for a regulation on the addition of vitamins and minerals to foods with a view to harmonising legislation throughout member states of the EU (Commission of the European Communities, 2003), which is expected to be adopted in 2006. This has stimulated wide-ranging debate on the benefits, and possible risks, of voluntary fortification.

There are few studies on the impact of voluntary fortification of foods on micronutrient intakes. Sichert-Hellert *et al.* (2000) investigated 10-year trends (from 1987 to 1996) in vitamin and mineral intakes from fortified foods (FF) in children aged 2–13 years in Germany. FF included all products to which one or more vitamins were added, including mandatory additions, such as vitamins A and D added to margarines

(for the purposes of restoration) and vitamins and minerals added to children's foods under EU regulations. Over the 10-year period, the mean energy intake from FF increased from 6 to 9 % total energy and the percentage contribution of FF to total intakes of vitamins B_1, B_2 and B_6, folate, vitamin C and niacin increased from 8–19 in 1987 to 20–32 in 1995. There was little change in the contribution to vitamin E intake (about 27–30 %). A follow-up study (Sichert-Hellert *et al.* 2001) showed that the contribution of FF to energy and micronutrient intakes reached a plateau or decreased between 1994–1996 and 2000. These studies also showed that FF contributed a significant proportion of the total intakes of a number of vitamins for which mean intakes would otherwise have been 20–80 % of that recommended, including folate and vitamins A, B_1, C and E, suggesting that FF may make an important contribution to adequacy of intakes of these nutrients.

Berner *et al.* (2001) reported on the contribution of voluntary fortification to vitamin and mineral intakes in the United States between 1989 and 1991. For those aged >1 year, and excluding intakes from nutritional supplements, fortification increased the median intakes of vitamin A (by 21 %), vitamin C (25 %), thiamin (12 %), riboflavin (11 %), niacin (12 %), folate (23 %), Fe (14 %) and Zn (6 %), but did not

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affect intake of Ca. Increases were observed in all age and gender subgroups, especially in children. Although the effect of fortification on adequacy of nutrient intakes (relative to requirements) was not examined, in many cases, the added nutrients boosted the 25th percentile or median intakes from below to above the RDA.

Studies in a number of countries have shown that added nutrients in fortified ready to eat (RTE) breakfast cereals contribute significantly to the intakes of several micronutrients in different population groups (Crawley, 1993; Sommerville & O'Reagan, 1993; McNulty *et al.* 1994, 1996; Gibson & O'Sullivan, 1995; Ortega *et al.* 1996; Ruxton *et al.* 1996; Preziosi *et al.* 1999; Galvin *et al.* 2003; Gibson, 2003). For example, McNulty *et al.* (1994) showed that the added nutrients in RTE breakfast cereals made a significant contribution to mean daily intakes (MDI) of thiamin, riboflavin, niacin, vitamins B_6, B_{12}, C, D, folic acid and Fe in British adults aged 18–64 years.

McNulty *et al.* (1996) reported that lower proportions of school children aged 12–15 years, who consumed fortified RTE breakfast cereals, had intakes of several B-vitamins and Fe less than the lower reference nutrient intake, compared with non-consumers.

In Ireland and the UK, the voluntary addition of vitamins and minerals to foods has been permitted for many years and a significant number of foods and beverages are now fortified (British Nutrition Foundation, 1994; Richardson, 1997). However, the impact of such fortification on micronutrient intakes and adequacy of intakes has not been assessed adequately. In the present paper, the contribution of FF to MDI of macronutrients and micronutrients is reported and the effect of voluntary fortification of foods on micronutrient intakes, adequacy of intakes and the risk of excessive intakes in 18–64 year old Irish adults is also reported.

Methods

The food consumption and nutrient intake database

This analysis was performed using data from the North/South Ireland Food Consumption Survey (Irish Universities Nutrition Alliance, 2001), which collected food intake data in a representative sample of 18–64 year old adults (*n* 1379: 662 men; 717 women) in the Republic of Ireland and Northern Ireland from 1997 to 1999. Pregnant and lactating women were excluded. A 7-d estimated food diary was used to measure food intake and a database of habitual food and drink consumption was established. A more detailed account of the methodology of the survey (Harrington *et al.* 2001) and the sampling procedure (Kiely *et al.* 2001) is provided elsewhere.

Food records were analysed using WISP© (Tinuviel Software, Warrington, UK). WISP© uses McCance and Widdowson's Composition of Foods, 5th edition (Holland *et al.* 1995) and supplemental volumes (Holland *et al.* 1988, 1989, 1991, 1992, 1993, 1996; Chan *et al.* 1994, 1995, 1996), food and nutrient database, along with additional data (including analysed recipes of composite dishes, manufacturers' data on generic Irish foods, new products that were commonly consumed and nutritional supplements) to determine nutrient intakes. The data handling, processing and quality control procedures used in the construction of the food consumption and nutrient

intake database have been described in detail elsewhere (Harrington *et al.* 2001).

Identification of fortified foods

Foods contained in the database that are fortified were identified from the presence of vitamins and/or minerals in the ingredient list on the label. For the purposes of this paper 'fortification' refers to the voluntary addition of micronutrients by food manufacturers, which is identified in product labelling and excludes (semi) mandatory addition of micronutrients to foods (e.g. vitamins A and D to fat spreads and low-fat milk) to ensure 'nutritional equivalence' and vitamins and minerals added to flour for the purposes of 'restoration'. These are considered 'indigenous' for the purposes of this discussion. The nutrient composition data were revised for many FF (e.g. many of the RTE breakfast cereals) using up-to-date manufacturers' data. New FF were assigned new food codes with corresponding nutrient composition data from manufacturers.

Pre-fortification levels of micronutrients in FF were obtained from: (a) manufacturers, (e.g. many of the RTE breakfast cereals); (b) compositional data for an unfortified equivalent of the food contained in the database (e.g. breads, milks, carbonated beverages).

The quantity of each micronutrient in FF products per typical serving was estimated and expressed as % of the EC RDA, i.e. the reference value used for nutrition labelling (European Commission, 1990). Typical servings were obtained from manufacturers' typical serving sizes as indicated on food labels or, if these were not present, from published typical weights and portion sizes (Ministry of Agriculture, Fisheries & Food, 1993).

The food consumption database generated from the survey listed each individual food item as consumed by each respondent, together with the nutrient composition for the quantity of each food consumed. Respondents who consumed a FF at any time during the 7 d of recording were classified as consumers of FF.

Adequacy of micronutrient intakes

The average requirement (AR), as estimated by the EC Scientific Committee for Food (1993) was used as a cut-point to estimate the proportion of a 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 (Carriquiry, 1999). 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 (Food and Nutrition Board, 1997). 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, the estimation of the level of inadequacy by this method is most accurate if intakes and requirements of the nutrient are independent of each other, if the standard deviation of intakes is at least twice as large as the standard deviation of requirements, and if the requirements are symmetrically (but not necessarily normally) distributed.

The estimate of nutrient intake should represent habitual intake. Misreporting of food consumption can influence the accuracy of the estimate of adequacy, resulting in an underestimate or an overestimate depending on the direction of the bias (Carriquiry, 1999). Hannon *et al.* (2001) and O'Brien *et al.* (2001) reported that the standard deviation of the mean intakes of vitamins and minerals in this population sample were greater than the commonly assumed standard deviation of requirement of 15 % of the mean (Scientific Committee for Food, 1993). It is generally assumed that for vitamins and minerals the intakes are independent of requirements and that the requirements for vitamins and minerals are symmetrically distributed, except for Fe in menstruating women (Hannon *et al.* 2001). The skewed distribution of Fe requirements in menstruating women results in an underestimate of the prevalence of inadequate Fe intakes using the cut-point method (Food and Nutrition Board, 2000). Bingham *et al.* (1994) compared a number of dietary assessment methods to 16-d weighed records. With a 7-d estimated food diary, as used in this survey, individual values of nutrients were most closely associated with those obtained from the weighed record. It is a useful means of measuring habitual intake with regard to most vitamins and minerals except for nutrients, for which a significant contribution to the MDI is made by rich dietary sources that are consumed on an irregular basis (e.g. retinol). The prevalence of inadequate intakes of micronutrients was calculated both including and excluding under-reporters of energy intake, identified as having a ratio of energy intake:BMR of < 1·05 (Black, 2000). Under-reporting leads to an overestimate of the prevalence of inadequate intakes. The data presented include under-reporters (20 % of total sample), as removal of under-reporters did not change the overall trends observed.

A range of recommended intakes has been established for vitamin D (0–10 μg) depending on sunlight exposure (Food Safety Authority of Ireland, 1999). In the absence of an AR, the percentage with MDI of vitamin D < 5 μg was reported. In the absence of an AR for vitamin E, the lowest threshold intake was used as a cut off value, i.e. the intake level below which nearly all individuals will be unable to maintain metabolic integrity according to the criterion used for each nutrient (Scientific Committee for Food, 1993). The lowest threshold intake can be used to identify individuals with a very high probability of inadequate intakes. While it is of limited value for assessing the prevalence of nutrient inadequacy in populations, a high proportion of individuals with MDI of a nutrient below the lowest threshold intake would indicate that the prevalence of inadequacy in the population is significant.

Folate and risk of neural tube defects

The potential impact of increased folic acid intake from FF on reduction of risk of neural tube defects (NTD) in infants was estimated using the method of Daly *et al.* (1995, 1997). These data describe: (a) the relationship between maternal folate status (as determined by red cell folate measurement) and the risk of NTD (Daly *et al.* 1995); (b) the relationship between additional intake of folic acid (100 μg, 200 μg and 400 μg as supplements) and median red cell folate in women. The effect of additional folic acid intake from FF on red cell folate was estimated by linear extrapolation from the median red cell folate values provided by 100 μg, 200 μg and 400 μg supplements of folic acid used by Daly *et al.* (1997). The percentage reduction in the risk of NTD was then estimated with reference to the data of Daly *et al.* (1995).

Excessive micronutrient intakes

The risk of excessive intake of a micronutrient was evaluated by expressing the 95th percentile of intake (P95) as a percentage of the tolerable upper intake level (UL). The UL is defined as the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects to man (European Food Safety Authority, 2006). The UL for adults (recently published by the European Food Safety Authority (2006)) for retinol (3000 μg), vitamin D (50 μg), vitamin E (300 mg), vitamin B_6 (25 mg), folic acid (1000 μg), Ca (2500 mg) and Zn (25 mg) were used. For pre-formed niacin, the UL for nicotinamide (900 mg) was used, since this is the form generally added to foods. No UL were established for vitamins B_1, B_2, B_{12}, pantothenic acid or biotin due to lack of evidence of adverse effects associated with high levels of intake. For Fe and vitamin C, the available data were considered insufficient to establish a UL (European Food Safety Authority, 2006).

Data analysis

Data analysis was conducted using SPSS® for Windows™ Version 11.0 (SPSS Inc., Chicago, IL, USA). Data were analysed both including and excluding the fortification component.

Results

Micronutrient content of fortified foods

The survey database contained 2914 food codes that were recorded as consumed, as well as 146 nutritional supplements. Fifty-four products were fortified at the time of the present study (1·9 % of those consumed). The main categories of foods that were fortified were cereals, mainly RTE breakfast cereals, and drinks (Table 1). Thiamine, riboflavin, Fe, niacin, folic acid, vitamins B_{12}, B_6, D and pantothenate were the nutrients most commonly added to foods, while Ca, vitamin C, vitamin E, retinol, Zn and biotin were added to few foods (Table 1).

The percentage of the EC RDA of different micronutrients per typical serving of FF products is presented in Fig. 1. The median value for percentage of the EC RDA per typical serving of FF varied from between 18 and 19 % (P25 16–18 %; P75 20–25 %) for Fe, vitamin D, Zn and biotin to 28 % for vitamin C (P25 25 %; P75 50 %) and 33 % for Ca (P25 17 %; P75 44 %).

Table 2 shows that 65 % of men and 68 % of women consumed one or more FF; 61 % of men and 63 % of women consumed fortified RTE breakfast cereals. In the total population, MDI of energy from FF was 283 kJ (P95 1017 kJ) in men and 256 kJ (P95 843 kJ) in women, corresponding to 2·6 % (P95 8·8 %) of the total MDI of energy in men and 3·4 %

Table 1. Food groups containing fortified foods (FF), number of foods per food group that were fortified, nutrients added and number of foods these nutrients were added to

Food group	No. of FF per food group	Nutrients added and numbers of foods these nutrients were added to
Cereals		
Ready to eat breakfast cereals	38	Vitamin B2 (38), Vitamin B1 (38), Fe (38), Folic acid (35), Vitamin B12 (34), Vitamin B6 (34), Niacin (33), Vitamin D (12), Pantothenic acid (8), Vitamin C (5), Vitamin E (3), Zn (2), Biotin (1), Retinol (1).
Other breakfast cereals	1	Vitamin B1 (1), Vitamin B2 (1), Vitamin B6 (1), Pantothenic acid (1), Fe (1), Folic acid (1), Ca (1), Vitamin B12 (1), Niacin (1).
Cereal bars	1	Vitamin B1 (1), Vitamin B2 (1), Vitamin B6 (1), Fe (1), Folic acid (1), Ca (1), Vitamin B12 (1), Niacin (1).
Bread	2	Vitamin B1 (2), Niacin (2), Fe (2), Folic acid (2), Ca (2), Vitamin B2 (1), Retinol (1), Vitamin D (1).
Spaghetti in tomato sauce	1	Vitamin B1 (1), Vitamin B2 (1), Niacin (1), Fe (1), Vitamin B12 (1), I (1).
Beverages		
Fortified milks	4	Vitamin D (4), Ca (2), Retinol (2), Vitamin B2 (1), Vitamin B12 (1), Folic acid (1), Vitamin E (1).
Other beverages*	7	Niacin (5), Vitamin B6 (5), Vitamin B2 (4), Vitamin B12 (4), Vitamin B1 (4), Pantothenic acid (4), Folic acid (3), Vitamin C (3), Ca (2), Retinol (2), Vitamin D (1), Zn (1), Biotin (1), Carotene (1).
All FF	54	Vitamin B2 (47), Vitamin B1 (47), Fe (44), Folic acid (43), Niacin (43), Vitamin B12 (42), Vitamin B6 (41), Vitamin D (18), Pantothenic acid (13), Ca (8), Vitamin C (8), Retinol (6), Vitamin E (6), Zn (3), Biotin (2), Carotene (1), I (1).

*Includes squashes, fruit juice drinks, carbonated and powdered beverages.

(P95 11·7 %) in women. In consumers of FF, the percentage of the total MDI of energy from FF was 3·9 % (P95 10·1 %) in men and 5·0 % (P95 13·3 %) in women. In consumers, fortified RTE breakfast cereals contributed 3·8 % (P95 9·3 %) of the MDI of energy in men and 4·8 % (P95 12·6 %) in women.

Contribution of fortified foods to energy and macronutrient intakes

The percentage contribution of FF to MDI of energy and macronutrients is shown in Table 3. Relative to their contribution to MDI of energy, FF contribute less to MDI of protein (men 2·7 %; women 3·8 %) and fat (men 0·7 %; women 1·1 %) and more to MDI of carbohydrate (men 6·9 %; women 8·2 %), total sugars (men 4·0 %; women 5·3 %) and starch (men 8·8 %; women 10·2 %) (Table 3).

Contribution of fortified foods to micronutrient intakes

Among consumers, FF make significant contributions to MDI of Fe, folate, vitamin B_2, thiamin, vitamin B_6, vitamin D, niacin and vitamin B_{12}. Most of this contribution was attributable to the added micronutrients (Table 4).

The effect of fortification on the MDI of micronutrients was examined at the 5th, 50th and 95th percentiles. As Zn, biotin, carotene and I are infrequently added to foods, additions of these nutrients were found to have little or no impact on MDI in the current analysis. Table 5 shows that, in male consumers of FF, the median intakes (when added nutrients in FF were not included) of folate, vitamins B_2, B_1 and B_6 were 82 %, 86 %, 86 % and 88 %, respectively, of the median intakes when these nutrients were included. Similarly, in female consumers of FF, the median intakes (when added nutrients in FF were not included) of vitamin D, folate, vitamins B_1 and B_2, Fe and vitamin B_6 were 81 %, 83 %, 84 %, 84 %, 85 % and 85 %, respectively, of the median intakes when the added nutrients were included. In both men and women, increases in MDI of nutrients at the 5th and 95th percentiles of intake were of a similar magnitude to the increases observed at the median.

Effect of fortification on adequacy of micronutrient intakes

We previously showed that intakes of several nutrients were inadequate in Irish adults, particularly Ca, Fe, vitamin D and folate in women and riboflavin and vitamin D in men and women (Hannon *et al.* 2001; O'Brien *et al.* 2001). Table 6 shows that, in consumers of FF, the addition of riboflavin, folic acid and Fe reduced the proportion of men and women with inadequate intakes of these nutrients, as defined by the percentage of individuals whose MDI was less than the AR. The addition of Ca and vitamin C to foods had little impact on the prevalence of inadequate intakes. The proportion of consumers of FF with a MDI of riboflavin below the AR decreased from 16 to 7 % in men and from 26 to 12 % in women, when added riboflavin was included. The percentage of women with inadequate Fe intakes decreased from 49 to 31 (from 59 to 38 % in 18–50 year old women) when added Fe was included.

Similarly, fortification reduced the proportion of women (18–64 years) with a MDI of folate below the AR from 12 to 3 % and by a similar amount in 18–50 year old women only. However the AR for 18–50 year old women does not
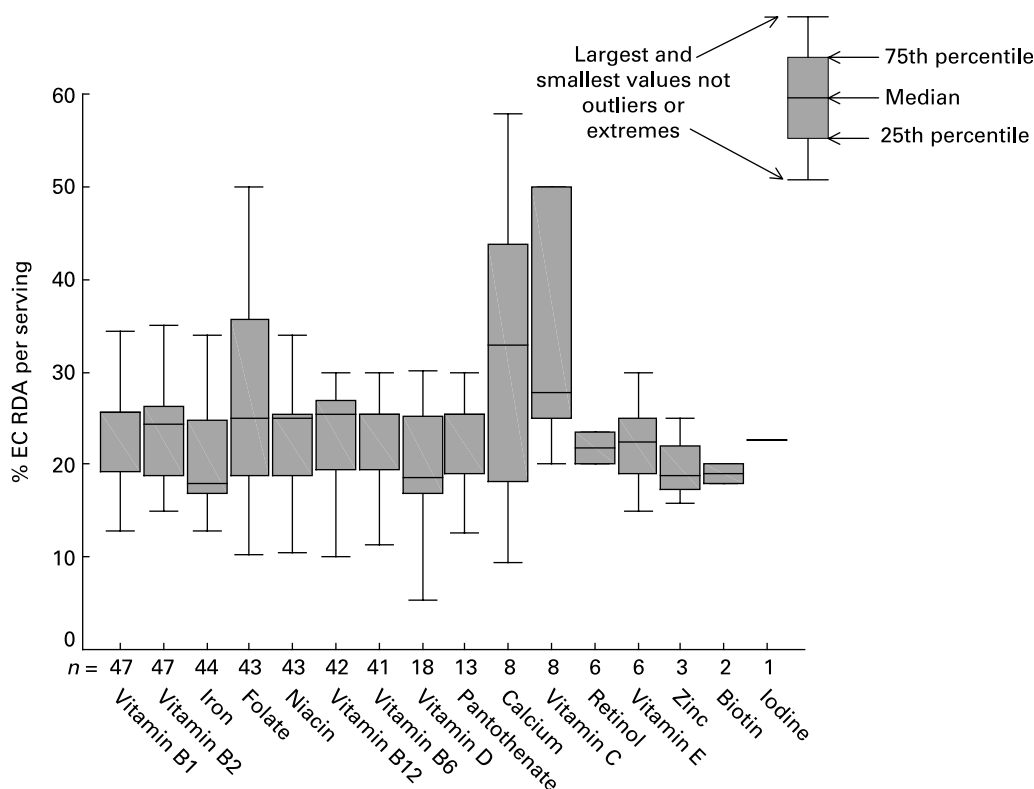
Fig. 1. Micronutrient content (% EC recommended daily amount (RDA)) in an average serving of fortified food.

include the additional folate recommended for prevention of NTD (Committee on Medical Aspects of Food & Nutrition Policy, 2000) and it was estimated that the mean additional folic acid intake from fortification in this group (49 μg) would achieve a reduction of about 12 % in risk of NTD.

In the absence of an AR for vitamin D, the percentage with MDI less than 5 μg (the midpoint of the recommended range for adults of 0–10 μg/d) was obtained including added vitamin D (80 % and 79 % in men and women, respectively) and excluding added vitamin D (78 % and 76 % in men and women, respectively). Added vitamin E had little effect on the proportion of consumers of FF with mean daily vitamin E intakes below the lowest threshold intake (15 % and 9 % in men and women, respectively).

Risk of excessive intakes

Table 7 shows the effect of fortification on P95 of micronutrients as percentage of the UL. The P95 as percentage of the UL including fortification did not approach 100 % for any micronutrient and removing the added nutrient had little impact. A small proportion (0·1–2·2 %) of FF consumers had MDI of folic acid, vitamin B_6, retinol, Ca, Zn and vitamin E that exceeded the UL but this was not affected by exclusion of added nutrient from the analysis.

Discussion

In Ireland and the UK, the addition of nutrients to foods is not restricted in terms of the types of food, nutrients or levels of nutrients and is permitted provided it is not injurious to health and labelling does not mislead (Scientific Co-operation Task 7.1.1 Working Group, 1997). Almost 2 % of foods recorded as consumed in the North/South Ireland Food Consumption Survey of 18–64 year old adults were voluntarily fortified, 72 % of which were breakfast cereals and 20 % of which were drinks of different varieties, including milks, squashes, fruit juice drinks, carbonated and powdered beverages. The micronutrients most commonly added to foods were vitamins (riboflavin, thiamin, folic acid, niacin, vitamins B_{12} and B_6) and Fe, which were added to between 76 and 87 % of all FF. Fewer FF (11–33 %) contained vitamin D, pantothenic acid, Ca, vitamin C, retinol and vitamin E, while Zn, biotin, carotene and I were rarely added (less than 6 % of FF). FF contained moderate, but nutritionally significant amounts of micronutrients with the median content (as percentage of the EC RDA in an average serving) ranging from 18 % (Fe) to 33 % (Ca), while the P75 ranged from 20 % (biotin) to 50 % (vitamin C).

Among consumers (67 % of adults), FF contributed on average 4·5 % (P95 11·7 %) of total energy intake. Few estimates of the percentage energy from FF in populations have been made. The mean daily percentage energy from voluntarily FF in the total population was estimated at 3 % in the UK, based on household intake data from the National Food Survey 1999 (Ministry of Agriculture, Fisheries and Food, 200; Flynn *et al.* 2003). Sichert-Hellert *et al.* (2000, 2001) reported that the mean daily percentage energy from FF in German children and adolescents ranged from 6 to 9 %. However, this estimate includes foods with mandatory additions, e.g. margarines and children's foods fortified under EU regulation, as well as foods voluntarily fortified.

Table 2. Mean daily energy intake and % energy from fortified foods (FF) in men and women consumers of FF
(Mean values and standard deviations)

| | Men (n 428) | | | | | | | Women (n 485) | | | | | | |
| | % consumers | Energy intake (kJ) from FF | | | % energy from FF | | | % consumers | Energy intake (kJ) from FF | | | % energy from FF | | |
Food group		Mean	SD	P95	Mean	SD	P95		Mean	SD	P95	Mean	SD	P95
Cereals														
Ready to eat breakfast cereals	60·6	423	355	1090	3·8	2·9	9·3	63·2	362	293	910	4·8	3·8	12·6
Other breakfast cereals	1·1	187	145	406	1·9	1·2	4·0	1·0	130	92	298	1·8	1·5	4·2
Cereal bars	1·1	113	42	159	1·0	0·4	1·4	1·1	151	114	396	1·9	1·6	5·5
Bread	0·2	283	0	283	2·7	0·0	2·7	0·3	195	133	290	2·7	2·2	4·2
Spaghetti in tomato sauce	0·9	97	43	152	0·8	0·4	1·6	1·1	91	50	160	1·0	0·6	1·9
Beverages														
Fortified milks	2·7	396	258	1166	3·9	2·1	8·3	6·7	260	253	907	3·2	3·0	10·3
Other beverages*	6·5	151	130	459	1·3	1·2	3·5	4·6	111	114	416	1·7	1·8	6·4
All fortified foods	64·7	435	366	1118	3·9	3·1	10·1	67·6	377	309	966	5·0	4·0	13·3

* Includes squashes, fruit juice drinks, carbonated and powdered beverages.
P95, 95th percentile of intake.

Table 3. Percentage contribution of fortified foods to mean daily intakes of macronutrients, in consumers of fortified foods, by gender

| | % of total mean daily intake | |
Macronutrient	Men (n 428)	Women (n 485)
Energy	3·9	5·0
Protein	2·7	3·8
Fat	0·7	1·1
Carbohydrate	6·9	8·2
Total sugars	4·0	5·3
Starch	8·8	10·2

Among consumers, FF contributed a significant proportion (10–21 %) of the total intake of micronutrients more frequently added to foods, i.e. vitamins B_1, B_2, B_6, folate, niacin and Fe, and vitamin D in women, due mainly to the added micronutrients. For some micronutrients, the intake from FF reduced the prevalence of inadequate intakes, e.g. vitamin B_2 in men and women and folate, Fe and vitamin D in women only.

For folate, in women between the ages of 18–50 years fortification reduced the proportion with intakes less than the AR from 14 to 4 %. This AR (140 µg) does not take into account recommendations for an extra daily intake of 400 µg folic acid in addition to diet for women of reproductive years for the prevention of NTD in newborn infants (Food Safety Advisory Board, 1998; Committee on Medical Aspects of Food & Nutrition Policy, 2000). The mean additional folic acid intake from fortification in this group (49 µg) would achieve a reduction of about 12 % in risk of NTD-affected births, as estimated with reference to the data of Daly *et al.* (1995, 1997).

Table 4. Percent contribution of fortified foods to mean daily intakes of micronutrients from all sources, in consumers of fortified foods, by gender

| | % of total mean daily intake | |
Micronutrient	Men (n 428)	Women (n 485)
Minerals		
Ca	2·4	3·6
Mg	4·6	7·0
P	3·2	5·2
Fe	15·7	19·1
Cu	3·6	4·7
Zn	3·2	5·5
Vitamins		
Retinol	1·6	2·7
Carotene	0·2	0·2
Total vitamin A	1·0	1·6
Vitamin D	4·5	11·3
Vitamin E	2·4	3·4
Vitamin B1	14·0	16·4
Vitamin B2	15·9	18·3
Total niacin equivalents	9·5	11·7
Vitamin B6	11·9	14·7
Vitamin B12	5·4	7·1
Total folate	18·4	20·9
Biotin	2·8	4·5
Pantothenic acid	3·2	4·8
Vitamin C	1·7	3·4

Table 5. Effect of nutrient addition on intakes of micronutrients from all sources at the 5th (P5), 50th (P50) and 95th (P95) percentiles in men and women consumers of fortified foods

| | Men (n 428, 65 % of all men) | | | | | | Women (n 485, 68 % of all women) | | | | | |
| | Added nutrients not included | | | Added nutrients included | | | Added nutrients not included | | | Added nutrients included | | |
Micronutrient	P5	P50	P95	P5	P50	P95	P5	P50	P95	P5	P50	P95
Retinol (μg)	140	394	1535	142	396	1560	105	308	1900	105	320	1900
Vitamin D (μg)	1·1	2·7	9·2	1·1	2·8	10·1	0·7	1·9	10·4	0·7	2·3	11·5
Vitamin E (mg)	2·6	6·2	17·2	2·6	6·3	17·3	2·4	5·7	22·9	2·4	5·9	25·3
Vitamin B1 (mg)	1·0	1·9	3·5	1·2	2·2	4·0	0·8	1·4	3·2	1·0	1·6	3·5
Vitamin B2 (mg)	1·0	1·8	3·4	1·2	2·1	4·0	0·8	1·4	3·3	0·9	1·6	3·7
Total niacin equivalents (mg)	28·2	45·0	73·3	30·6	48·5	76·3	20·4	32·0	52·5	22·0	34·6	55·1
Vitamin B6 (mg)	1·6	2·8	5·5	1·8	3·2	6·4	1·1	1·9	5·4	1·4	2·2	5·4
Vitamin B12 (μg)	2·2	4·5	10·5	2·4	4·7	10·9	1·2	3·2	9·3	1·4	3·5	9·4
Folate (μg)	148	275	485	182	336	584	120	205	492	148	246	581
Pantothenic acid (mg)	3·4	6·0	11·1	3·6	6·1	11·2	2·6	4·3	10·4	2·8	4·4	10·7
Vitamin C (mg)	26	75	324	26	76	331	27	70	247	28	73	247
Ca (mg)	501	946	1613	502	951	1648	402	720	1209	402	729	1209
Fe (mg)	6·9	12·6	23·6	7·9	14·2	27·2	5·5	9·2	24·6	6·6	10·9	27·1

While the additional folic acid derived from FF in men and women (about 40–60 μg/d increases in median intake) is sufficient to improve folate status (Cuskelly *et al.* 1999), it is probably not sufficient to significantly reduce plasma homocysteine (Malinow *et al.* 1998), which is a risk factor for CHD (Boushey *et al.* 1995), dementia and Alzheimer's disease (Seshadri *et al.* 2002).

In the case of Fe, fortification reduced the proportion of women aged 18–50 years with intakes less than the AR from 60 to 40 %. These values may be underestimates since the skewed distribution of Fe requirements in menstruating women results in an underestimate of the prevalence of inadequate Fe intakes using the cut-point method (Food and Nutrition Board, 2000). Low Fe status is prevalent among women in developed countries. One in three Irish women have inadequate Fe stores and about one in thirty have Fe-deficiency anaemia, which exists when the blood haemoglobin levels are reduced below optimal levels (Cahill, 1995). In women aged 18 to 64 years, 26 % and 13 % had borderline Fe stores and anaemia, respectively (Gibson, 2003), as measured in the Dietary and Nutrition Survey of British Adults (Gregory *et al.* 1990). In the USA NHANES III (1988–1994), the prevalence of Fe deficiency and anaemia

were 9–11 % and 2–5 %, respectively, in women of childbearing age (Looker *et al.* 1997).

For vitamin D, fortification contributed 11 % of total vitamin D intake and increased the median daily intake by 23 % from 1·9 to 2·3 μg in women. This contribution from fortification may be important given the low median intakes of vitamin D in women relative to the acceptable range of intake of 0–10 μg/d (Food Safety Authority of Ireland, 1999). Significant proportions (34 to 64 %) of Irish adults have inadequate vitamin D status (defined as serum 25 (OH) D levels < 50 nmol/l) (Hill *et al.* 2006), a finding that is in agreement with evidence of a significant prevalence of low vitamin D status in adults in other European countries, e.g. 14 % in France (Chapuy *et al.* 1997), 39 % in Spain (Mezquita-Raya *et al.* 2001) and 26–29 % in Finland (Lamberg-Allardt *et al.* 2001).

The contribution of FF to intakes of vitamins B_1, B_6, B_{12} and niacin, although significant in relation to total intake, appears to be of little public health importance since dietary intake of these nutrients is already adequate in this population group. However, other population groups may benefit from the inclusion of some of these micronutrients in FF, e.g. low status for vitamins B_6 (Bailey *et al.* 1997; Pentieva *et al.* 1999) and

Table 6. Effect of fortification on percentage of consumers with inadequate micronutrient intakes (i.e. % with mean daily intakes less than the average requirement*) from all sources

| | | % with inadequate intakes | | | |
| | | Men (n 428) | | Women (n 485) | |
Nutrient	Average Requirement*	Added nutrients not included	Added nutrients included	Added nutrients not included	Added nutrients included
Riboflavin	1·3 (1·1) mg	16·4	7·2	25·8	12·2
Folate	140 μg	4·0	0·7	12·4	3·3
Vitamin C	30 mg	8·2	7·9	6·6	5·6
Fe	7 (10†, 6‡) mg	5·1	1·4	49·3	30·7
Ca	550 mg	8·2	7·7	17·9	17·1

* EC Scientific Committee for Food, 1993; values for women are shown in parentheses.
† Menstruating
‡ Postmenopausal women.

Table 7. Effect of fortification on 95th percentile (P95) of micronutrient intake as percentage of tolerable upper intake level (UL)* in fortified food consumers

		P95 as %UL*			
		Men (*n* 428)		Women (*n* 485)	
Nutrient	UL*	Added nutrients not included	Added nutrients included	Added nutrients not included	Added nutrients included
Retinol	3000 μg	51·2	52·0	63·3	63·3
Vitamin D	50 μg	18·4	20·2	20·9	22·8
Vitamin E	300 mg	5·7	5·8	7·6	8·3
Vitamin B6	25 mg	21·9	25·7	21·4	21·7
Folic acid	1000 μg	12·4	24·1	29·6	36·8
Pre-formed niacin	900 mg†	4·9	5·3	3·9	4·2
Ca	2500 mg	64·5	65·9	48·4	48·4
Zn	25 mg	86·2	86·2	65·7	65·7

* European Food Safety Authority, 2006.
† Nicotinamide.

B_{12} (Hin *et al.* 2006) have been reported in UK elderly. Fortification had little impact on the intake or prevalence of inadequate intakes of Ca, vitamin C or vitamin E, as these nutrients were added to foods less frequently.

The estimates of the prevalence of inadequate intakes of micronutrients in the present study do not take account of the effect of under-reporting food intake. However, while removal of under-reporters (15 % of men and 24 % of women) from the analysis resulted in a decrease in the percentage with inadequate intakes of micronutrients, it did not change the overall trends observed with regard to the impact of fortification on the prevalence of inadequacy. For example, in women aged 18–64 years, fortification reduced the prevalence of inadequate intakes from 49 to 31 % when under-reporters were included and from 43 to 23 % when under-reporters were excluded from the analysis.

The present study did not examine the effect of FF on micronutrient status. However, a number of studies have reported a positive association between intakes of a number of B-vitamins (e.g. folate, riboflavin, vitamin B_{12}) from FF and status (Preziosi *et al.* 1999; Cuskelly *et al.* 1996, 1999; Gibson, 2003), but this was not observed for Fe, possibly due to lower meat consumption in those consuming higher levels of Fe from FF (Gibson, 2003). Work with stable isotopes has quantified the bioavailability of Fe from breakfast cereals at around 3 %, although this is doubled if a source of ascorbic acid is consumed at the same meal (Fairweather-Tait *et al.* 1995).

FF consumption was not associated with increased risk of adverse effects for any micronutrient. The 95th percentile of intake of micronutrients (as %UL) from all sources in men and women did not exceed, or even approach, the UL for any micronutrient, with or without the inclusion of fortification in the estimate of intakes. This indicates a very low risk of adverse effects from excessive intakes of micronutrients in the population. A small proportion (0·1–2·2 %) of FF consumers had MDI of folic acid, vitamin B_6, retinol, Ca, Zn, and vitamin E that exceeded the UL but this was mainly associated with the use of nutritional supplements (Kiely *et al.* 2001) or, in the case of retinol, of high liver consumption and was not affected by fortification, which contributed only small amounts to the intakes of these micronutrients relative to their UL. For example, 1·2 % of FF consumers (mainly women) exceeded the UL for vitamin B_6 (25 mg) with average daily intakes ranging from 30–62 mg, mainly from supplements, while one FF consumer (male) exceeded the UL for Ca (2500 mg) with an average daily intake of 2929 mg, mainly from milk.

The results presented in this paper serve to inform the debate on the benefits, and possible risks, of voluntary fortification of foods. Analysis of data on food and nutrient intakes in a nationally representative sample of 18–64 year old adults living in Ireland, where the voluntary fortification of foods with micronutrients is freely permitted, has shown that voluntary fortification of foods makes a significant contribution to the intakes of a range of micronutrients in the population and improves the adequacy of intake of some micronutrients, particularly of riboflavin, folate, vitamin D and Fe in women. While addition of some frequently added nutrients, e.g. niacin, is of little relevance for public health, more frequent addition of nutrients such as Ca and vitamin D would be beneficial for this population group. Fortification does not contribute to an increased risk of adverse effects from excessive intake of any micronutrient.

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