Iron intake and iron status of preschool children: associations with breakfast cereals, vitamin C and meat

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Abstract

Objective: To examine associations between breakfast cereal consumption and iron status and identify dietary patterns that might improve iron status in this vulnerable group.

Design: Analysis of data from the UK National Diet and Nutrition Survey (NDNS) of children aged 1.5–4.5 years, including dietary intakes calculated from 4-day weighed records.

Subjects: Data were used from 904 children with haematological measurements, excluding those taking iron supplements; 20% had low iron stores (ferritin $< 10\ \mu g\ l^{-1}$) while 8% were anaemic (Hb $< 11\ g\ dl^{-1}$).

Results: High cereal consumers had significantly higher iron intakes than low cereal consumers (classified by tertiles) but the 10% difference in mean ferritin levels was not significant ($P = 0.067$). Lower intakes of vitamin C and meat among high consumers of cereal may have diluted the impact of cereal iron on iron status. When children were reclassified according to their intakes of vitamin C and iron from meat and breakfast cereals, the group with high (above median) intakes of two or more factors had a higher mean haemoglobin (Hb) level and a lower prevalence of anaemia compared with the group with low (below median) intakes of all three dietary constituents.

Conclusions: Nutritional advice that aims to improve iron status should emphasize not only rich sources of iron but also factors that may enhance or inhibit absorption. Strategies to optimize iron status in this vulnerable age group include consuming an iron-fortified breakfast cereal, vitamin C-rich fruit or drink at breakfast, and avoiding tea with (or after) meals.

Keywords
Iron status
Diet
Children
Breakfast cereals
Bioavailability

In industrialized societies, where dietary iron intake and bioavailability are relatively high, there should in theory be no iron deficiency. However, certain groups are still vulnerable to iron deficiency due to the high requirements of tissue growth (children and adolescents), or high losses (women of childbearing age) or poor absorption[1]. In the recent NDNS of children aged 1.5–4.5 years, low iron stores (ferritin $< 10\ \mu g\ l^{-1}$) were found in 20% of the children surveyed, and iron deficiency anaemia (Hb $< 11\ g\ dl^{-1}$) in 8%[2]. This is not dissimilar to the levels of anaemia found in smaller surveys of preschool children in Bradford[3] and Birmingham[1]. The published report of the NDNS reported a weak correlation between total iron intake and haemoglobin ($r = 0.08$; $P < 0.05$), but no significant correlation with ferritin[2]. However, preliminary analyses for the present study revealed a positive association between iron intake and logarithmically-transformed values of ferritin ($r = 0.10$; $P = 0.002$) not reported previously.

There are several reasons, apart from measurement error, why associations between total iron intake and status measures are so weak. These include the fact that iron absorption is increased in individuals with low iron stores[4] and that iron bioavailability depends not only on the form of iron in foods, but on the presence of dietary enhancers or inhibitors of absorption in the meal. For example, a study of infants aged 4–18 months has recently reported an *inverse* association between iron stores (ferritin) and non-haem iron intake that, the authors suggest, reflects the low bioavailability of non-haem iron and the presence of inhibitory factors[5].

For children in the NDNS, breakfast cereals provided, on average, 20% of the total dietary iron intake[2]. The purpose of this study was to examine whether a high intake of breakfast cereals was associated with a more adequate iron intake and whether this was in turn reflected in better iron status. Other dietary differences between cereal consumption groups, their impact on iron intakes and association with iron status, were also explored. Finally, the combined impact of three dietary constituents (iron-fortified cereal, meat and vitamin C) on iron status was assessed.

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Methods

Survey design and methodology

The UK NDNS of children aged 1.5–4.5 years comprises the most recent nationally representative dietary survey of this age group for 25 years. The survey methodology is explained in full in the published reports, but briefly outlined below.

A nationally representative sample of 2101 children aged 1.5–4.5 years was identified from the postcode address file. Only children from private households were eligible and only one child from each household was selected. Interviews were conducted for 1859 of these children over a period of 12 months, and this interview sample was found to be sociodemographically representative with reference to the General Household Survey 1992. Dietary data was collected via a weighed record of all food and drink consumed by the child over 4 consecutive days (2 weekdays plus 2 weekend days); this was completed by the child's main carer, usually the mother. The detailed recording procedure was carefully demonstrated to participants by a fieldworker who visited homes several times to check recording and to probe for missing items. Details of cooking and preparation methods, leftovers, spillages and foods eaten away from home were recorded. A MAFF database, updated for the survey and comprising the nutritional composition of 6000 foods, was used to calculate nutrient intakes. In a feasibility study prior to the survey, the dietary method was validated by doubly labelled water (to measure energy expenditure). On average, the measures of intake and expenditure were extremely close, suggesting there was little underreporting.

The 4-day records were reweighed by the original investigators to provide estimates of consumption over a 7-day period (5 weekdays, 2 weekend days). Complete dietary records were obtained for 1675 children (90% of the interview sample). Blood was obtained, with parental written consent, from 1003 of these children and analysed within 24 hours. Haemoglobin was measured using a cyanomethaemoglobin colorimetric technique and plasma ferritin using the Becton–Dickinson ferritin monoclonal antibody assay. Zinc protoporphyrin was estimated using the Helena Protofluor, calibrated daily[2].

Data analysis

The computerized data files for the dietary survey were obtained from the Data Archive (ESRC, Colchester, Essex) and analysed using SPSS version 8 for Windows (SPSS, UK). Children in the youngest group (1.5–2.5 years) tended to have lower intakes of breakfast cereal, lower iron intakes and lower levels of haemoglobin and ferritin than older children (2.5–4.5 years). To avoid a spurious association between breakfast cereal intake and iron status, it was essential to adjust for age and energy intake in classifying children into low, average and high cereal consumption groups. The energy contribution of breakfast cereals was then calculated as a proportion of total daily energy intake for each child ($n = 1675$). Within each year group and sex (six groups) children were classified into one of three groups, corresponding to thirds of the distribution of energy from cereals for their group. These 18 groups were amalgamated to provide thirds of consumption that were comparable in their age distribution (e.g. the lowest third of each age and gender group were combined). To examine the influence of iron-fortified cereals, as well as cereals in general, the contribution of breakfast cereals to the iron intake of each child (cereal iron) was also calculated. Finally, median cut-offs for cereal iron, meat iron and vitamin C were used to classify children according to their intake of these three dietary constituents, with a maximum score of 3 corresponding to an above median intake of all three factors. Data shown in Tables 1–6 are for the subset of children for whom both ferritin and haemoglobin levels were measured, excluding the small number taking iron supplements ($n = 30$). These 904 children did not differ significantly from the total dietary sample in terms of age and cereal consumption.

Differences between the high, average and low breakfast cereal consumers were evaluated using one-way analysis of variance (ANOVA) for multiple comparisons and *t*-test (two-tailed) for two-group comparison. Non-parametric methods (Kruskal Wallis test and Mann–Whitney U-test) were used for assessing food intakes. Values of $P < 0.05$ were taken as statistically significant.

Results

Profile of cereal consumption groups

The characteristics of low, average and high consumers of breakfast cereals are shown in Table 1. The groups were age matched (mean age 35 months) and the proportion of children from manual households was not significantly different across the groups. On average, breakfast cereals provided 6% of the total daily energy intake. Children in the highest consumption group (group 3) consumed almost 11% of daily energy as cereals, or more than six times the proportion consumed by low/non-consumers (group 1). Mean weekly intakes of cereals in the low, average and high consumption groups were 42, 129 and 250 g, respectively. Only 67 out of the sample of 904 children (7%) did not eat any breakfast cereal at all in the 4 days of survey.

Table 1 Characteristics of children by level of cereal consumption

	Cereal consumption group*			Total	
	Low ($n=283$)	Average ($n=299$)	High ($n=322$)	Mean ($n=904$)	Median ($n=904$)
Cereal intake					
Percentage of energy from cereal					
Mean	1.6	5.4	10.6	6.0	5.5
SE	0.1	0.1	0.2	0.1	
Amount (all types) (g week^{-1})					
Mean	42	129	250	145	124
SE	3	3	8	3	
Of which:					
Non-wholegrain cereal (g week^{-1})					
Mean	20	61	100	62	36
SE	2	3	6	3	
High-fibre/wholegrain cereal (g week^{-1})					
Mean	22	68	150	83	43
SE	3	4	9	4	
Sociodemographic variables					
Age in months					
Mean	35	35	35	35	36
SE	1	1	1	1	
Non-manual (%)	50	47	49	49	
Manual (%)	50	53	51	51	

*Cereal consumption group calculated as thirds of consumption (percentage energy basis) for each age/gender group in the diet sample ($n=1675$). Data quoted are for those children with ferritin and Hb measurements ($n=904$).

Dietary differences between cereal consumption groups

The mean iron intake of high cereal consumers (5.92 mg day^{-1}) was significantly higher than that of low consumers (4.96 mg day^{-1}) ($P<0.0001$) (Table 2). However, this difference was smaller than that contributed by the additional breakfast cereals (1.6 mg day^{-1}), being partly offset by lower contributions from meat and other iron sources (Table 3). The lower intakes of meat explain the slightly (but not significantly) lower haem iron intakes among high consumers of cereal (Table 2). Vitamin C intakes were also inversely related to breakfast cereal consumption and this has implications for the absorption of non-haem iron. Energy intakes were on average 300 kJ lower among high cereal consumers compared with the low and average consumers (ANOVA $P<0.0001$). This explains, in part, the lower vitamin C intake in this group.

Differences in food intakes between low, average

Table 2 Mean intake of iron and selected nutrients by level of cereal consumption

	Cereal consumption group			Total		
	Low	Average	High	Mean	Median	ANOVA
Iron intake (mg day^{-1})						
Mean	4.96	5.41	5.92	5.45	5.27	$P<0.0001$
SE	0.10	0.10	0.10	0.06		
Haem iron (mg day^{-1})						
Mean	0.27	0.27	0.24	0.26	0.20	ns ($P=0.06$)
SE	0.01	0.02	0.02	0.01		
Non-haem iron (mg day^{-1})						
Mean	4.75	5.20	5.73	5.25	5.04	$P<0.0001$
SE	0.09	0.09	0.09	0.05		
Vitamin C (mg day^{-1})						
Mean	59	52	48	53	40	$P=0.008$
SE	3	3	2	2		
Non-starch polysaccharide (g day^{-1})						
Mean	5.8	6.2	6.5	6.2	5.9	$P=0.001$
SE	0.1	0.1	0.1	0.1		
Calcium (mg day^{-1})						
Mean	645	655	610	636	606	ns ($P=0.06$)
SE	17	15	12	8		
Energy (kJ day^{-1})						
Mean	4987	4924	4644	4844	4806	$P<0.0001$
SE	70	63	58	37		

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Table 3 Sources of iron according to cereal consumption level*

	Cereal consumption level			Total		Difference between low and high group, Mann-Whitney U-test
	Low	Average	High	Mean	Median	
Total iron intake (mg day^{-1})						
Mean	4.96	5.41	5.92	5.45	5.27	$P<0.0001$
SE	0.10	0.10	0.10	0.08		
Contribution (mg day^{-1}) of iron from:						
Meat and meat products						
Mean	0.82	0.81	0.69	0.77	0.63	$P=0.017$
SE	0.04	0.04	0.03	0.03		
Breakfast cereals						
Mean	0.35	1.10	1.95	1.17	0.99	$P<0.0001$
SE	0.02	0.03	0.06	0.03		
Biscuits and cakes						
Mean	0.48	0.45	0.38	0.44	0.36	$P=0.003$
SE	0.02	0.02	0.02	0.01		
Confectionery						
Mean	0.19	0.17	0.15	0.17	0.12	$P=0.025$
SE	0.01	0.01	0.01	0.01		
Savoury snacks						
Mean	0.14	0.11	0.10	0.12	0.08	$P<0.001$
SE	0.01	0.01	0.01	0.01		

*No significant difference between the groups for bread, rice and pasta, potatoes, vegetables, fish, eggs, milk or miscellaneous foods.

and high consumers of cereals are shown in Table 4. The proportion of breakfast cereal in the diet was positively associated with consumption of sugar and jam ($P=0.008$), but not milk ($P=0.53$) (data not shown). Children consumed an average of 289 ml (about 0.5 pint) of liquid milk per day whether their intake of cereals was low or high. Children with a high consumption of cereal had a significantly lower intake

Table 4 Food intakes (g week^{-1}) according to level of cereal consumption (total sample)

	Cereal consumption level			Total		Kruskall Wallis ANOVA
	Low	Average	High	Mean	Median	
Biscuits and cakes						
Mean	197	186	163	181	155	$P=0.016$
SE	9	8	7	5		
Confectionery						
Mean	162	152	127	147	110	$P=0.009$
SE	9	8	7	5		
Total fats						
Mean	51	41	39	43	35	$P<0.0001$
SE	2	2	2	1		
Fruit and nuts						
Mean	371	373	316	352	253	$P=0.024$
SE	23	21	19	12		
Meat and meat products						
Mean	387	367	334	362	311	$P=0.046$
SE	17	14	14	9		
Puddings*						
Mean	346	419	371	379	288	$P=0.029$
SE	22	23	19	12		
Soft drinks†						
Mean	3000	2866	2481	2771	2367	$P=0.029$
SE	154	123	109	74		
Sugar and jams						
Mean	29	28	39	32	19	$P=0.008$
SE	2	2	3	1		
Savoury snacks						
Mean	77	64	55	65	48	$P<0.0001$
SE	4	4	3	2		

Differences in intake of other foods were not statistically significant.
*Including yogurt, fromage frais and ice-cream.
†Soft drinks other than fruit juice.

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of fats ($P < 0.0001$) and of snack foods such as confectionery ($P = 0.009$), savoury snacks ($P < 0.0001$) and biscuits and cakes ($P = 0.016$), whose contribution to iron is shown in Table 3. Consumption of meat and meat products ($P = 0.046$) was also lower. The lower vitamin C intake of high consumers of cereals was due to lower intakes of both fruit ($P = 0.024$) and soft drinks (mainly fruit squashes; $P = 0.029$).

Associations between cereal consumption and iron status

Despite the difference in total iron intake between the cereal consumption groups, there was no significant difference in iron status as measured by plasma ferritin, haemoglobin or zinc protoporphyrin (ZPP), a functional indicator of an inadequate supply of iron. Plasma ferritin levels were around 10% higher among high consumers of cereals, but this just failed to reach statistical significance ($P = 0.067$) (Table 5). Log-transformation of the ferritin values likewise failed to show a positive association, neither was there a significant difference in the proportion of children with low levels of ferritin (< 12 or $< 20\ \mu g\ l^{-1}$). Neither haemoglobin concentration nor ZPP showed an association with cereal consumption level. Further analyses using data on the amount of iron derived from breakfast cereals also failed to show any significant relationships with ferritin haemoglobin or ZPP.

Dietary combinations and iron status

The final analyses attempted to remove the confounding caused by lower intakes of meat and vitamin C among high consumers of cereal and to investigate the impact of different levels of these three dietary constituents. Children were classified according to whether their intakes of vitamin C were above or below the reference nutrient intake (RNI) ($40\ mg\ day^{-1}$) (which was also the median intake) and above or below the median for meat iron ($0.63\ mg\ day^{-1}$), and iron from cereals ($0.99\ mg\ day^{-1}$). Children with above median intakes of vitamin C, meat iron *and* cereal iron had a significantly higher mean haemoglobin level compared with children who scored low on all three counts ($P = 0.004$) (Table 6). Of greater biological significance, the prevalence of anaemia (Hb $< 11\ g\ dl^{-1}$) in children with a score of 2 or more (6.5%) was only half that among children with a zero score (12.8%; $P = 0.025$) (Fig. 1). With ferritin levels there were trends in the same direction, but these failed to reach statistical significance (Table 6).

Discussion

Overall, the iron intakes in the NDNS averaged 82% of the RNI, slightly lower than those of 153 preschool children studied by Payne and Belton[6]. In the NDNS, children under 4 years of age appeared to be most at risk of poor iron intakes (16% below the RNI, compared with 4% of those aged 4 years and over)[2]. However, this difference in prevalence is largely explained by the fact that the RNI for iron reduces from 6.9 to $6.1\ mg\ day^{-1}$ at 4 years[1]. Breakfast cereals provided 20% of the total iron intake of the preschool children in the NDNS (meat provided 14%). For children consuming most breakfast cereals (top third), nearly one-third of the total daily iron intake was from this source. Total iron intake differed by 19% between the low and high breakfast cereal consumption groups ($P < 0.0001$).

Despite superior iron intakes among the high cereal consumers, none of the indices of iron status were significantly different between the cereal consumption groups. This is less surprising when viewed in the light of the poor correlation generally found between total iron intake and status[7–9]. The official report of the NDNS likewise reported a weak correlation between

Table 5 Haemoglobin and ferritin concentration by level of cereal consumption

	Cereal consumption group				
Index of iron status	Low	Average	High	Total	ANOVA
Haemoglobin ($g\ dl^{-1}$)					
Mean	12.2	12.1	12.2	12.2	ns
SE	0.1	0.1	0.1	0.0	
Ferritin ($\mu g\ l^{-1}$)*					
Mean	22.5	23.0	24.5	23.4	ns
SE	1.0	1.1	1.1	0.6	
Ferritin (log-base 10)					
Mean	1.24	1.24	1.27	1.25	ns
SE	0.02	0.02	0.02	0.01	
Zinc protoporphyrin ($\mu mol\ mol^{-1}$ haem)					
Mean	53	56	53	54	ns
SE	1.0	1.5	0.9	0.7	
% with haemoglobin $< 11\ g\ dl^{-1}$	7.4	8.7	8.4	8.2	Chi-square test: ns
% with ferritin values $< 12\ \mu g\ l^{-1}$	30	31	28	29	Chi-square test: ns

*The difference in ferritin level between low and high groups just failed to reach significance (*t*-test: $P = 0.067$).

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Table 6 Mean value of iron status indices and prevalence of anaemia (Hb $< 11\,g\,dl^{-1}$) according to dietary score†

Iron status indices	Dietary score 0 ($n=109$)	1 ($n=346$)	2 ($n=335$)	3 ($n=115$)
Mean haemoglobin ($g\,dl^{-1}$)	11.9	12.1	12.2	12.3**
Mean ferritin ($\mu g\,l^{-1}$)	22.6	22.1	24.0	26.3
Mean zinc protoporphyrin ($\mu mol\,mol^{-1}$ haem)	56	54	55	51
% of children with haemoglobin $< 11\,g\,dl^{-1}$	12.8	9.0	6.6*	6.1*
% of children with ferritin $< 12\,\mu g\,l^{-1}$	33.9	30.6	27.2	27.8
% of children with ferritin $< 10\,\mu g\,l^{-1}$	23.9	22.8	18.6	18.3

†Score calculated according to whether individual has above median intake of three dietary factors: vitamin C, iron from cereals and iron from meat (see text).
Values significantly different from dietary score of 0; *$P=0.025$; **$P=0.004$ (Bonferroni test).

iron intake and haemoglobin ($r=0.08$; $P<0.05$) and non-significant correlations with ferritin and ZPP[2]. However, on log-transforming ferritin values to near-normality and adjusting for age and energy intake, a positive correlation was revealed with iron intake ($r=0.10$; $P=0.002$) that has not been reported previously. Thus an analysis of the associations between cereal consumption and iron status was thought justified, although the relationships were expected at the outset to be very weak. Host-related factors further reduce the ability to detect diet–status associations in studies of iron status, while recent infection can artificially elevate ferritin levels[10,11]. However, exclusion of children with high levels of acute phase proteins (α-antichymotrypsin values $> 0.65\,g\,l^{-1}$) did not alter the associations found in this study (data not shown).

The fact that blood measurements were only obtained on around 60% of the children completing dietary diaries raises the question of the generalizability of the results. Examination of the samples with and without blood measurements indicated, however, that there were no significant differences in age or intakes of iron, vitamin C, cereals or meat, nor in the prevalence of illness on any day of the survey. Underreporting was a consideration in the original survey, and it was concluded from the validation study that measurements of intakes and expenditure were very close, although lower than the estimated average requirements (EARs). In the present study, a supplementary analysis excluding those children with energy intakes of less than 75% of the EAR did not alter the relationships found.

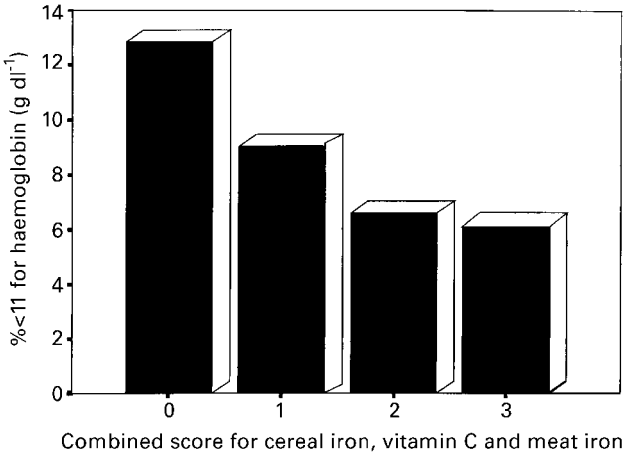

Fig. 1 Prevalence of anaemia according to intake of cereal iron, vitamin C and meat iron. Children with a score of 2 or more had significantly less anaemia (prevalence 6.5%) than those with a score of 0 (prevalence 12.8%) ($P=0.025$). Score 0 = below median intake of all three factors; score 3 = above median intake of all three factors

The superior iron intakes of the children consuming most cereals were offset by other dietary habits (a lower intake of meat and a lower vitamin C intake) that would have reduced iron bioavailability. Some of this confounding was removed in the analysis that evaluated the combined impact of these three dietary factors. Children with high intakes of cereals who *also* had adequate vitamin C intakes *and* above average meat intakes had the highest haemoglobin levels and lowest prevalence of anaemia. These findings are similar to those of Nelson *et al.*, who found in their study of Surrey school children (12–14 years) that girls with a high intake of both iron and vitamin C had significantly higher haemoglobin levels compared with those with low intakes of both nutrients[12]. Interestingly, in both Nelson *et al.*'s study and this one, ferritin levels were less well predicted by the combined classification.

The conclusions of the present study differ from those of Wharf *et al.*, who found cereal consumption to be *inversely* associated with iron status in very young children[5]. They attributed this to reduced bioavailability of high cereal diets. In the present study, dietary inhibitors of iron absorption could have weakened the association between iron intake and iron status. High cereal consumers had a higher intake of non-starch polysaccharides, but this is not thought to reduce mineral bioavailability except where phytate is also high[13]. Phytate intakes were not measured in the present survey, but the phytate content of processed cereals consumed by children is likely to be low.

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Furthermore, vitamin C counteracts the effect of phytate in a dose-dependent manner[14,15] but would have to be consumed at the same meal.

The significance of calcium as an inhibitor remains a matter of debate. Several epidemiological studies in Europe have reported negative correlations between serum ferritin and intakes of calcium or dairy products[11,16–18] but other dietary differences could explain some of these associations. High calcium foods have also been shown to inhibit iron absorption in laboratory experiments in humans[19], and reducing the cheese and milk content of iron-containing meals has been demonstrated to enhance bioavailability[20]. On the other hand it has been argued that the longer-term effect in mixed diets may be much less than that suggested by absorption studies involving single meals[21]. At present, dietary advice to limit milk and milk products in the diets of young children is not warranted as the benefits outweigh any putative detrimental effect on iron absorption. Consumption of tea, however, is one habit that may be amenable to modification or re-timing. Tea contains polyphenolic compounds that form iron complexes, from which iron is poorly absorbed[22]. Interestingly, although most young children consume very little tea, there was an inverse association in the present study between tea consumption and (log)ferritin ($r=-0.09$, $P<0.007$; data not shown). For optimal iron absorption, tea should therefore be avoided with, or after, meals.

A limitation of the present study is that the influence of inhibitors and enhancers of iron absorption could not be evaluated within meals. Despite the more crude 'total diet' approach, however, some associations were found. An analysis by meal occasions, if feasible, would be predicted to show stronger diet–status associations than those detected here.

In conclusion, to optimize iron status it is still desirable to encourage a varied diet with adequate attention to sources of haem iron, but more emphasis should be given to the enhancing or inhibitory factors influencing non-haem iron absorption. Fruit drinks containing vitamin C have been shown to enhance iron absorption from weaning foods[23] and consuming breakfast cereals with a source of vitamin C such as fresh fruit or a fruit-based drink could improve iron availability and, potentially, iron status. Consideration could also be given to broadening the scope of iron fortification to include those whole-grain cereals that are presently unfortified and to consider adding vitamin C to formulations, particularly where phytates are present. This study suggests that a more holistic emphasis is required to improve iron status—one that includes consideration of dietary patterns that enhance bioavailability—rather than focusing on iron intake alone. There is still a need to quantify the influence of dietary and non-dietary factors (and their interactions) via controlled laboratory studies, but these have to be complemented by intervention trials to establish the actual impact of foods and diets on the iron status of free-living people.

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