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Dietary iron intake over two post-fortification periods in Brazil: data from the National Dietary Surveys 2008–2009 and 2017–2018

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Abstract

We aimed to assess the dietary Fe intake and the prevalence of inadequate Fe intake over two post-fortification periods in Brazil. The intake was analysed according to sex, life stage, geographic region and stratum of family income per capita. Excluding pregnant and lactating women, this population-based study included 32 749 and 44 744 participants aged ≥ 10 years from the National Dietary Survey-Brazilian Household Budget Surveys 2008–2009 and 2017–2018, respectively. The National Cancer Institute method was used to predict usual dietary Fe intakes. The prevalence of Fe intake inadequacy was estimated following a probabilistic approach for women of childbearing age or with the Estimated Average Requirement cut-off point method. Over an interval of 10 years, the mean Fe intake remained almost unchanged for most sex-age groups, except for women of childbearing age. In this specific group, the prevalence of Fe intake inadequacy was > 20 % in 2008–2009 and have increased to > 25 % in 2017–2018, with the highest reductions in mean Fe intake found in the highest income strata and richest Brazilian regions. Meanwhile, the highest prevalence of Fe intake inadequacy (> 40 %) occurred among the poorest women aged 31–50 years from the lowest family income stratum, irrespective of the study period. Beans were the main Fe source, while fortified breads, pastas, pizzas, cakes and cookies contributed approximately 40 % of the Fe intake. The results provide important insights into the long-standing dietary impacts of food fortification, which can guide future (re)formulation of effective public health strategies to combat Fe deficiency.

Key words: Iron: Food fortification: Epidemiological surveys

Fe deficiency remains one of the most serious and prevalent health problems worldwide, with > 1·1 billion individuals experiencing more severe haematological manifestations, that is, Fe deficiency anaemia[1,2]. Additionally, a higher number of cases, which remain unclear, are undiagnosed with depleted body Fe stores due to an absence of abnormal concentrations of Hb[1]. Despite the contrast in the main underlying aetiologies between developed and developing countries, the majority of Fe deficiency cases result from insufficient Fe intake and/or bioavailability to cover the body requirements of high-risk groups, especially preschool children and women of childbearing age[1]. According to the Global Burden of Disease Study, Fe deficiency was ranked as the leading risk factor attributable to years lived with disability burden among adolescents and young adults in 2019[3]. This is not surprising, owing to the primordial roles of body Fe not only in oxygen transport but also in various physiological and cellular processes, such as energy production, immunity, neurotransmission, and DNA synthesis and repair[4].

Dietary Fe can be found in the form of the highly bioavailable haem, exclusively present in animal tissues, and in various forms of non-haem, widely distributed in both animal- and plant-derived foods[4]. Mandatory or voluntary Fe fortification of staple foods, especially grains and condiments, is an interventional strategy adopted by many countries as part of public health policies aimed at preventing Fe deficiency[5]. Therefore, iron-fortified wheat and maize products, rice, breakfast cereals, infant formulas, oil, and salt may also contribute to increasing the dietary Fe intake of populations[5,6]. Iron-fortified foods are present in > 87 countries despite greatly varying in their contribution to the RDA across high-, middle-, and low-income settings and were presumed to prevent > 4 million cases of Fe deficiency anaemia among women of childbearing age in 2021[6].

Abbreviations: FR, Food Record; HBS, Household Budget Survey; IOM, Institute of Medicine; NDS, National Dietary Survey; 24hR, 24-hr recall.

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In Brazil, fortified wheat and maize flours have been mandated since July 2004 by a law that requires the provision of at least 30 % of the RDA of Fe for healthy male and women adults in each serving of 100 g of these foods/ingredients (4·2 mg of iron/100 g of flour)(7). According to the WHO, a decreasing trend in the prevalence of low Hb levels among women of childbearing age occurred in the country from 2004 (24·9 %) to 2018 (16·2 %)(8). However, no nationally representative data on biomarker changes in population Fe status have been assessed following the implementation of the fortification programme, precluding conclusions on its real effectiveness in preventing Fe deficiency(9). As an alternative and complementary evaluation in this regard, data on post-fortification dietary Fe intake inadequacy of adolescents, adults and elderly individuals were assessed in the first National Dietary Survey-Brazilian Household Budget Survey (NDS-HBS) performed in 2008–2009(10–13). With a new, recently released edition of the NDS-HBS(14), it is now possible to assess the long-term trends of the impact of food fortification on dietary Fe intake across the country.

Hence, the present study aimed to assess the dietary Fe intakes and the prevalence of inadequate Fe intake over two distinct post-fortification periods (2008–2009 and 2017–2018) in Brazil according to sex, life stage, geographic region and stratum of family income per capita. We intend to provide scientific evidence to better comprehend dietary Fe intake data in different contexts and consequently guide the (re)formulation of effective public health strategies to combat Fe deficiency.

Methods

Study population and design

The NDS are part of the HBS 2008–2009 and HBS 2017–2018, the two most recent nationwide surveys conducted by the Brazilian Institute of Geography and Statistics (IBGE) using household samplings to measure living conditions, incomes, expenditures and consumption profiles of families(13,14). Both HBS had two-stage cluster sampling, in which census sectors and households were randomly selected with geographical and socio-economic stratifications of the primary sampling units based on the 2000 Demographic Census. Subsamples of 13 569 and 20 112 households from 55 970 (24·2 %) and 57 920 (34·7 %) households included in the HBS were randomly selected for the NDS 2008–2009 and NDS 2017–2018, with food consumption data collected from all residents aged ≥ 10 years, totalling information from 34 003 and 46 164 individuals, respectively. Presently, we excluded pregnant and lactating women (n 1254 in 2008–2009 and n 1420 in 2017–2018), totalling 32 749 and 44 744 individuals, respectively, in the final samples.

Dietary intake assessment

In both surveys, individual food consumption was assessed on two non-consecutive days, selected during the week in which the researcher agent visited the household, with weekdays and weekends being represented throughout the 12 months of the survey period: May 2008 to May 2009 (NDS 2008–2009) and July 2017 to July 2018 (NDS 2017–2018). Details on data collection, training, quality control and imputation can be found in the official IBGE publications(13,14).

In 2008–2009, the instrument used was food records (FR). Individuals were instructed to record all foods and beverages consumed throughout the day (97 % responded to a second food record), including details on eating time, occasion and place, recipes, ingredients, and food preparation methods, with portion sizes preferably quantified in household measures. During household interviews, all recorded information was reviewed, completed when necessary, and typed by research agents on a specific data entry programme installed on tablets(13).

In 2017–2018, the 24-h recalls (24hR) were used. Individuals were asked to report all food and beverages (including water) consumed during the previous day in an in-person structured interview (84 % responded to a second 24hR), following the US Department of Agriculture (USDA) Automated Multiple-Pass Method(15). While the interviewee reported the data uninterruptedly, the interviewer made a quick list on paper, registering eating time, occasion and place. Similar to the previous survey, research agents used a specific data entry programme installed on tablets to detail data from the quick list, including recipes, ingredients, food preparation methods, portion sizes in household measures and items added to foods(14).

The food and beverage intake databases had 1503 items in the NDS 2008–2009 and 1832 items in the NDS 2017–2018(16). To estimate the amounts consumed of each food or beverage, in both surveys, the Table of Reference Measures for Food Consumed in Brazil developed in NDS 2008–2009 and reviewed and updated in NDS 2017–2018 was used(17). This tool is a compilation of data from national tables of household measurements, food labels, scientific articles and direct weight measurements performed in research centres at Brazilian universities. This table provides the mass units (g) of each food and beverage referred in the two surveys(17). Dietary Fe intake was calculated using the Brazilian Food Composition Table (TBCA-USP), version 7.0(18). This database considers both the intrinsic Fe content of all foods and added Fe from the national mandatory fortification(19). Supplemental Fe was not evaluated in the present study.

Statistical analysis

The National Cancer Institute method was used to estimate the distributions of usual dietary Fe intake, accounting for within-person variation, using a mixed-effect model after the Box-Cox transformation(20). Model parameters (population mean, within- and between-person variances, and lambda value for the Box-Cox transformation) were estimated on the basis of data from the two FR or 24hR and then used to create usual consumption distributions, employing Monte Carlo simulations. Data were estimated for the entire population and by strata of sex-age, income and geographic regions. Sex-age groups were categorised, as defined by the US Institute of Medicine (IOM), into 10–13 years, 14–18 years, 19–30 years, 31–50 years and ≥ 51 years old(4). Geographic regions were categorised as north, northeast, southeast, south and central-west, and income strata as <0·5, 0·5 to 1, 1 to 2, and > 2 per capita minimum wage (equivalent to R$ 415·00 or U$$ 174·40 on 15 January 2009, and R$ 954·00 or U$$ 298·50 on 15 January 2018).

Dietary Reference Intake values proposed by the IOM were used as criteria to estimate the probability of individuals not meeting dietary Fe requirements, that is, the prevalence of inadequate Fe intake. A feasible way to estimate is to calculate the proportion of a population with usual intake levels below its respective Estimated Average Requirement, provided that the following assumptions are satisfied: (a) the distribution of nutrient intake is independent of the distribution of requirement; (b) the distribution of nutrient requirements is symmetrical; and (c) the distribution of nutrient requirements has lower variance compared with the distribution of nutrient intakes(21). Considering Fe data from the analysed sex-age groups, the Estimated Average Requirement cut-off point method could not be employed among women of reproductive age (14–50 years old), as the distribution of Fe requirement is skewed. Therefore, in this group, it was necessary to use a full probabilistic approach attaching the probability of inadequacy to each individual's usual Fe intake, considering the distribution of Fe requirement for the specific population. The prevalence of inadequate Fe intake was then calculated as the average risk of inadequacy for all individuals in the population group(21).

Particularly, the Fe requirement distributions employed in the probabilistic approach were calculated by weighing specific IOM reference values for users and non-users of hormonal contraceptives according to their respective prevalence among Brazilians women aged 14–18 years (23·9 % and 76·1 %), 19–30 years (49·5 % and 50·5 %) and 31–50 years (26·1 % and 73·9 %), as described in a national representative study performed in 2013–2014(22). This modification was adopted considering that menstrual blood losses are approximately 60 % lower among hormonal contraceptives users. Thus, IOM's reference values proposed for a mixed population would overestimate Fe requirements in our setting, since it assumes that more than 80 % of adolescent and adult women are naturally menstruating and do not use hormonal contraceptives(4).

The Brazilian surveys have a slightly different design from that used in the National Cancer Institute method. A variation of the Balanced Repeated Replication method, known as Fay's Balanced Repeated Replication method, was used to calculate 95 % CI(23). The results of 95 % CI were used to compare dietary values across sex-age, region and income groups, as well as between survey periods. These statistical analyses were performed with the aid of the SAS® software of the SAS System for Windows, version 9.4.

To estimate the major contributors to the total Fe intake in each survey, food items were categorised according to their conceptual and nutritional similarities, following an original proposal of IBGE(13), with adaptations to aggregate iron-poor food groups (i.e. coffee and tea, soda and other non-alcoholic beverages, and vegetables, leaves, roots, and soups) and to disaggregate iron-rich food groups (i.e. meats and fortified maize flour recipes). The final twenty food groups considered in the analyses were alcoholic drinks, added sugars and sweeteners, beans, breads, cakes and cookies, cassava flour and farofas, dairy products, eggs, fish and seafood, fortified maize flour recipes, fruits and nuts/seeds, red meats, non-alcoholic beverages, offal, oils and fats, pasta and pizza, poultry, processed meats, rice and other cereals, and soups, roots and vegetables. The contribution of each food group to the total Fe intake was estimated for the entire population as well as according to sex, age, income and geographic region groups using the approach proposed by Block *et al.*(24). All analyses were performed weighted and taking into account the complexity of the surveys with the aid of STATA® Statistics/Data Analysis software, version 14.2.

Results

As presented in Table 1, mean Fe intakes of Brazilians aged ≥ 10 years were 11·5 mg/d in 2008–2009 and 10·9 mg/d in 2017–2018, without a significant difference in the estimated overall prevalence of inadequacy between the two periods (12·9 %; 95 % CI 12·1, 13·6 *v.* 14·1 %; 95 % CI 13·4, 14·7, respectively). Nevertheless, when assessing sex-age groups, significant variations in overall Fe intakes between 2008–2009 and 2017–2018 were found for women, except those aged 10–13 and 19–30 years, with the highest relative increase in inadequacy values occurring among adolescents aged 14–18 years (22·0 %; 95 % CI 17·8, 26·2 *v.* 30·6 %; 95 % CI 29·5, 31·8, respectively). Meanwhile, the overall highest prevalence of Fe intake inadequacy was observed among women aged 31–50 years in 2017–2018 (37·0 %; 95 % CI 34·9, 39·2).

Individuals classified in the first stratum of family income per capita had lower Fe intakes in comparison with counterparts of the same sex and age groups, with prevalence of inadequacy reaching above 40 % among women aged 31–50 years, but without significant variations between the studied periods (Tables 2 and 3). In this regard, increases in inadequate Fe intakes over time were found only among women aged 14–18 years with family income per capita classified from the second stratum, from the third stratum on for women aged 31–50 and ≥ 51 years, and in the fourth stratum for women aged 19–30 years (Table 2).

When exploring regional differences, it was found that variations between 2008–2009 and 2017–2018 in the prevalence of Fe intake inadequacy among women occurred in all Brazilian regions for adolescents aged 14–18 years, but only in the southern region for adults aged 31–50 years and in the southeast region for adults of all age groups (Table 4). Furthermore, in the last region, a slight increase (< 0·5 percentage point) in the prevalence of Fe intake inadequacy was found for adult men aged 19–30 years (Table 5). Exceptionally, a slight reduction (< 2·0 percentage points) in the prevalence of Fe intake inadequacy over time was found among males aged ≥ 51 years from the northeast region (Table 5).

The top five food groups contributing to approximately 70 % of Fe intake in the entire Brazilian population were beans (all types of beans and peas, dishes prepared with beans and peas, and vegetable proteins), breads (all types of whole and white breads), red meats (all cuts of beef, pork, lamb, and goat), pasta and pizza (all types of pasta, pizzas, sandwiches, and fried or baked cafeteria items), and cakes and cookies (all types of cakes, cookies and crackers), both in 2009–2008 and 2017–2019, but with some regional variation in their respective ranking positions (Table 6). Particularly in the southern region,

Table 1. Mean Fe intake (mg/d) and prevalence of inadequate Fe intake (%) according to sex and age groups in the National Dietary Survey: 2008–2009 and 2017–2018

	2008–2009					2017–2018				
Sex-age groups	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI
Men										
10–13 years	1515	11·9	11·5, 12·3	3·7	2·6, 4·7	1730	11·8	11·4, 12·1	3·2	2·6, 3·8
14–18 years	1905	13·6	13·1, 14·0	6·5	4·5, 8·5	2196	12·9	12·7, 13·1	7·8	6·6, 8·9
19–30 years	3756	13·6	13·4, 13·8	1·5	1·4, 1·7	4173	13·2	13·0, 13·4	1·5	1·3, 1·8
31–50 years	5064	13·0	12·9, 13·1	2·2	1·9, 2·4	6887	12·7	12·5, 12·9	2·1	1·7, 2·4
≥ 51 years	3460	11·6	11·5, 11·7	4·6	4·0, 5·2	6474	11·4	11·2, 11·5	4·5	4·2, 4·8
Women										
10–13 years	1566	11·1	10·9, 11·3	4·9	4·2, 5·5	1519	10·8	10·3, 11·3	4·6	3·4, 5·8
14–18 years	1811	11·4	10·8, 11·9	22·0	17·8, 26·2	2071	10·1	10·0, 10·3	30·6	29·5, 31·8
19–30 years	3787	10·6	10·5, 10·8	24·6	23·6, 25·5	3958	10·2	9·9, 10·5	26·7	24·7, 28·7
31–50 years	5804	10·2	10·1, 10·3	32·2	31·0, 33·4	7982	9·5	9·2, 9·8	37·0	34·9, 39·2
≥ 51 years	4081	9·5	9·4, 9·6	6·5	5·8, 7·1	7754	8·9	8·7, 9·0	8·1	7·6, 8·7
All	32 749	11·5	11·4, 11·6	12·9	12·1, 13·6	44 744	10·9	10·8, 11·1	14·1	13·4, 14·7

Table 2. Mean Fe intake (mg/d) and prevalence of inadequate Fe intake (%) among men according to age and family income per capita groups in the National Dietary Survey: 2008–2009 and 2017–2018

	2008–2009					2017–2018				
Age and income groups	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI
First stratum (< 0·5 minimum wage)										
10–13 years	622	10·9	10·4, 11·4	5·9	3·5, 8·3	600	11·1	10·9, 11·4	4·5	3·6, 5·4
14–18 years	619	12·2	11·6, 12·8	11·3	7·6, 15·1	701	12·2	11·8, 12·5	10·7	8·8, 12·6
19–30 years	849	12·1	11·8, 12·4	3·3	2·7, 4·0	943	12·3	12·1, 12·5	2·5	1·9, 3·1
31–50 years	1089	11·5	11·3, 11·8	4·6	3·6, 5·6	1314	11·8	11·5, 12·1	3·2	2·3, 4·2
≥ 51 years	407	10·1	9·7, 10·4	9·7	7·6, 11·7	616	10·5	10·2, 10·7	7·1	5·9, 8·3
Second stratum (0·5–1 minimum wage)										
10–13 years	454	12·3	11·9, 12·7	2·7	2·1, 3·3	562	12·0	11·6, 12·5	2·8	2·0, 3·5
14–18 years	591	13·8	13·5, 14·1	5·7	4·5, 6·8	723	13·1	12·7, 13·5	6·8	5·3, 8·3
19–30 years	1020	13·6	13·2, 14·0	1·4	1·2, 1·6	1252	13·3	13·0, 13·6	1·3	0·9, 1·7
31–50 years	1314	13·0	12·8, 13·2	2·0	1·6, 2·3	1884	12·8	12·6, 12·9	1·8	1·5, 2·1
≥ 51 years	807	11·4	11·2, 11·6	4·7	4·2, 5·3	1421	11·4	11·3, 11·6	4·3	3·9, 4·7
Third stratum (1–2 minimum wages)										
10–13 years	283	12·7	12·2, 13·1	2·3	1·3, 3·3	388	12·1	11·6, 12·6	2·4	2·0, 2·8
14–18 years	432	14·2	13·8, 14·5	4·6	3·2, 6·0	536	13·2	12·9, 13·6	6·7	5·8, 7·7
19–30 years	1019	14·0	13·8, 14·1	1·1	0·9, 1·3	1199	13·4	13·0, 13·8	1·3	1·0, 1·5
31–50 years	1348	13·3	13·2, 13·5	1·7	1·4, 1·9	2097	12·9	12·6, 13·2	1·9	1·5, 2·2
≥ 51 years	1178	11·8	11·6, 12·0	3·9	3·2, 4·6	2442	11·4	11·1, 11·8	4·2	3·7, 4·7
Fourth stratum (> 2 minimum wages)										
10–13 years	156	12·7	12·3, 13·2	2·4	1·4, 3·4	180	12·1	11·7, 12·5	2·3	1·6, 3·1
14–18 years	263	14·3	14·0, 14·5	4·7	3·7, 5·7	236	13·3	12·9, 13·6	6·1	4·2, 8·0
19–30 years	868	14·0	13·7, 14·3	1·0	0·9, 1·1	779	13·4	13·0, 13·8	1·3	0·9, 1·6
31–50 years	1313	13·4	13·2, 13·7	1·6	1·4, 1·8	1592	12·9	12·6, 13·1	1·8	1·4, 2·2
≥ 51 years	1068	11·9	11·7, 12·0	3·7	3·3, 4·2	1995	11·4	11·3, 11·6	4·1	3·8, 4·5

iron-fortified foods contributed to total Fe intakes ranked above beans, with breads leading in 2008–2009 and pasta and pizza in 2017–2018. In turn, only in the central-west region, red meat had a contribution to total Fe intake higher than breads in both assessed periods (Table 6).

Both in 2008–2009 and in 2017–2018, the pattern of food Fe sources was comparable across sex (online Supplementary Table 1) and age groups (online Supplementary Table 2), while contrasts in the contribution of beans to the total mineral intake were found among individuals in the fourth stratum of family income per capita (about 16 %) compared with others (about 25 %) (online Supplementary Table 3). However, over the studied periods, few variations occurred in the ranking of food Fe source relevancy across sex, age and income groups (online Supplementary Tables 1, 2 and 3).

Discussion

The dietary Fe intake of Brazilians aged ≥ 10 years remained almost unchanged over an interval of 10 years in the post-fortification era, according to data from the two largest national

Table 3. Mean Fe intake (mg/d) and prevalence of inadequate Fe intake (%) among women according to age and family income per capita groups in the National Dietary Survey: 2008–2009 and 2017–2018

	2008–2009					2017–2018				
Age and income groups	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI
First stratum (< 0·5 minimum wage)										
10–13 years	622	10·2	9·9, 10·4	7·6	6·4, 8·8	600	10·2	9·8, 10·7	6·5	4·9, 8·1
14–18 years	619	10·3	9·6, 10·9	29·9	24·7, 35·2	701	9·5	9·3, 9·6	35·8	33·7, 37·9
19–30 years	849	9·4	9·2, 9·7	33·4	31·0, 35·9	943	9·5	9·2, 9·8	31·9	29·4, 34·4
31–50 years	1089	9·0	8·7, 9·3	42·2	39·3, 45·1	1314	8·8	8·6, 9·0	43·1	41·0, 45·1
≥ 51 years	407	8·2	7·8, 8·6	12·8	10·0, 15·7	616	8·1	7·9, 8·4	12·4	10·2, 14·7
Second stratum (0·5–1 minimum wage)										
10–13 years	454	11·4	11·0, 11·7	3·9	3·0, 4·8	562	11·1	10·7, 11·6	3·7	2·8, 4·7
14–18 years	591	11·5	11·2, 11·9	21·0	18·5, 23·5	723	10·3	10·1, 10·5	28·8	27·2, 30·4
19–30 years	1020	10·7	10·5, 10·9	24·2	23·2, 25·3	1252	10·4	10·0, 10·7	25·6	23·4, 27·8
31–50 years	1314	10·2	9·9, 10·4	32·1	30·3, 33·9	1884	9·6	9·3, 9·9	36·0	33·8, 38·3
≥ 51 years	807	9·3	9·1, 9·5	6·9	6·3, 7·5	1421	8·9	8·7, 9·0	8·1	7·4, 8·8
Third stratum (1–2 minimum wages)										
10–13 years	283	11·8	11·6, 12·0	3·1	2·4, 3·8	388	11·1	10·5, 11·8	3·7	2·3, 5·0
14–18 years	432	11·9	11·3, 12·5	18·8	15·1, 22·4	536	10·4	10·1, 10·7	28·0	26·1, 29·8
19–30 years	1019	11·0	10·8, 11·1	22·2	21·2, 23·2	1199	10·4	10·0, 10·9	25·2	22·6, 27·8
31–50 years	1348	10·5	10·4, 10·7	29·6	28·4, 30·8	2097	9·7	9·2, 10·1	35·5	32·2, 38·8
≥ 51 years	1178	9·6	9·4, 9·8	5·8	4·9, 6·6	2442	8·9	8·7, 9·2	7·7	6·9, 8·5
Fourth stratum (> 2 minimum wages)										
10–13 years	156	11·8	11·5, 12·1	3·1	2·3, 3·9	180	11·1	10·7, 11·6	3·3	2·3, 4·4
14–18 years	263	11·9	11·6, 12·2	18·6	16·0, 21·2	236	10·4	10·1, 10·7	28·0	25·4, 30·7
19–30 years	868	11·0	10·8, 11·2	21·9	20·9, 22·9	779	10·4	10·1, 10·8	25·3	23·0, 27·7
31–50 years	1313	10·6	10·4, 10·7	29·3	28·5, 30·1	1592	9·7	9·3, 10·0	35·5	32·8, 38·2
≥ 51 years	1068	9·7	9·5, 9·8	5·4	4·9, 5·9	1995	8·9	8·8, 9·1	7·6	6·8, 8·4

surveys of food consumption. However, a trend for an increase in the prevalence of Fe intake inadequacy was found between 2008–2009 and 2017–2018 among menstruating adolescent and older adult women, despite few variations in the relative contribution of major iron-sourced foods. Hence, the inadequacy of Fe intake among women of childbearing age, which was already concerning in 2008–2009, remained high in 2017–2018, with more than one-quarter showing inadequacy irrespective of the studied income strata and Brazilian regions.

The estimated mean dietary Fe intakes, after stratifying by sex-age groups, ranged from 9·5 to 13·6 mg/d in 2008–2009 and from 8·9 to 13·2 mg/d in 2017–2018. Despite a lack of national population-based Fe intake data from the pre-fortification era, our mean values showed similarities to those described by Vieira *et al.* (2017) and Sales *et al.* (2021) for representative samples of adolescents, adults and elderly residents in São Paulo-SP, the largest Brazilian city, in 2008 (7·8 to 15·2 mg/d)(25) and in 2015 (7·8 to 12·0 mg/d)(26), while significantly higher from those found in 2003 (3·9 to 7·0 mg/d)(25). These data are in line with improvements in Fe intake and population status among countries that have adopted strategies for flour fortification with Fe(27). However, recent mean Fe intakes of Brazilians are consistently below those described for North Americans of similar sex-age groups in the National Health and Nutrition Examination Survey (NHANES) 2017–2018 (11·6 to 16·8 mg/d)(28), despite exposure to similar amounts of Fe added to flours by mandated fortification (4·2 *v.* 4·4 mg/100 g, respectively)(7,29).

Irrespective of sex-age groups, the highest prevalence of Fe intake inadequacy was found among individuals from the lowest family income stratum (< 0·5 wage per capita), both in 2008–2009 and in 2017–2018. Socio-economic disparities have already been described in the same population for the intake of other micronutrients, such as vitamin C, vitamin A, riboflavin and thiamine(30). This is despite iron-rich sources such as beans, breads and beef being among the top six most commonly consumed foods in Brazil(31), even among the poorest stratum of the population(14). National data suggest that, in 2009 and in 2017–2018, 13 % and 14 % of Brazilians were experiencing quantitative food restriction or disruption in eating patterns resulting from the lack of food, respectively(32). Low energy and micronutrient intake associated with severe food insecurity have been described by Kubo *et al.* using data from the NDS-HBS 2008–2009(33). Although poor food consumption cannot be explained by socio-economic restriction alone, it is worth to noting that the highest Fe intake inadequacy observed here among women aged 31–50 years from the lowest stratum of family income (> 40 %) was similarly described in that survey among menstruating women in the highest quartile for food insecurity risk(33). These findings suggest that, along with the fortification policy, any strategy that aims to improve Fe intake in Brazil needs to emphasise on the equitable physical and financial access of the most disadvantaged population to regular and sufficient high-quality foods.

Contrastingly, while Fe intake did not significantly vary among the poorest, the most important reductions were paradoxically found among the wealthiest women. This was especially true for menstruating adolescent and adult women aged 31–50 years from the two upper-strata of family income, for which inadequacy figures increased by approximately 50 % and 20 % from 2008–2009 to 2017–2018, respectively. Accordingly, significant Fe intake differences over time were

Table 4. Mean Fe intake (mg/d) and prevalence of inadequate Fe intake (%) among women according to age and Brazilian geographic regions groups in the National Dietary Survey: 2008–2009 and 2017–2018

	2008–2009					2017–2018				
Region and age groups	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI
North										
10–13 years	305	10·4	10·2, 10·7	6·5	5·5, 7·5	303	10·4	9·9, 11·0	5·7	4·1, 7·4
14–18 years	301	10·8	10·4, 11·2	25·9	22·5, 29·3	390	9·7	9·3, 10·0	33·7	30·6, 36·9
19–30 years	603	10·1	9·9, 10·2	28·3	27·2, 29·3	686	9·9	9·5, 10·3	29·3	26·1, 32·6
31–50 years	814	9·6	9·5, 9·7	36·8	35·7, 37·9	1126	9·1	8·7, 9·5	40·2	36·7, 43·7
≥ 51 years	462	8·8	8·7, 8·9	9·1	8·3, 10·0	793	8·5	8·1, 8·9	9·9	7·6, 12·2
Northeast										
10–13 years	600	10·5	10·3, 10·7	6·4	5·8, 7·1	568	10·7	10·3, 11·1	4·8	3·9, 5·8
14–18 years	702	10·8	10·3, 11·3	26·0	21·6, 30·3	782	10·0	9·9, 10·1	31·5	30·4, 32·6
19–30 years	1504	10·1	9·9, 10·2	28·4	27·2, 29·7	1423	10·1	9·9, 10·4	27·3	25·6, 29·0
31–50 years	2079	9·6	9·3, 9·8	36·8	34·7, 38·9	2843	9·4	9·2, 9·6	37·9	36·6, 39·2
≥ 51 years	1482	8·9	8·7, 9·0	9·1	8·1, 10·0	2665	8·8	8·7, 8·8	8·7	7·6, 9·7
Southeast										
10–13 years	295	11·6	11·4, 11·8	3·5	2·9, 4·1	319	10·9	10·2, 11·6	4·3	2·4, 6·2
14–18 years	372	11·9	11·3, 12·4	19·2	15·4, 23·0	446	10·2	9·9, 10·5	29·6	27·4, 31·8
19–30 years	699	11·1	10·9, 11·2	21·8	20·8, 22·7	925	10·3	9·8, 10·7	26·3	23·4, 29·3
31–50 years	1332	10·6	10·4, 10·7	29·3	28·2, 30·4	1978	9·6	9·1, 10·0	36·4	33·0, 39·8
≥ 51 years	1032	9·8	9·7, 9·9	5·1	4·4, 5·8	2190	8·9	8·6, 9·2	7·9	7·2, 8·5
Southern										
10–13 years	167	11·5	11·1, 11·8	3·8	2·6, 5·0	150	11·0	10·6, 11·4	4·2	3·2, 5·2
14–18 years	206	11·8	11·4, 12·2	19·6	16·5, 22·7	210	10·3	9·9, 10·8	28·9	25·6, 32·2
19–30 years	435	11·1	10·9, 11·2	21·8	20·7, 22·9	441	10·4	10·1, 10·8	25·4	22·9, 27·8
31–50 years	741	10·5	10·3, 10·7	29·7	28·3, 31·1	1030	9·7	9·4, 10·0	35·5	33·1, 37·9
≥ 51 years	561	9·8	9·7, 9·9	5·4	4·7, 6·1	1215	9·0	8·7, 9·3	7·4	5·9, 9·0
Central-west										
10–13 years	199	10·9	10·5, 11·2	5·6	4·6, 6·5	179	10·9	10·5, 11·4	4·0	2·9, 5·1
14–18 years	230	11·1	10·6, 11·5	24·2	20·6, 27·7	243	10·2	10·0, 10·3	30·4	28·7, 32·0
19–30 years	546	10·4	10·1, 10·6	26·1	24·6, 27·7	483	10·3	9·9, 10·6	26·4	24·1, 28·7
31–50 years	838	9·8	9·6, 10·1	34·7	33·1, 36·4	1005	9·5	9·2, 9·8	36·8	34·3, 39·3
≥ 51 years	544	9·1	9·0, 9·3	7·5	6·5, 8·4	891	8·9	8·7, 9·1	8·1	7·1, 9·1

more pronounced among women from the wealthiest Brazilian regions (southeast and southern) relative to those from the poorest regions (north and northeast). Possible explanations for these results might be related to previously described socio-demographic disparities in the nutritional transition-related trends of substituting traditional staple Brazilian foods, such as rice and beans, for more convenient alternative items, such as ready-to-eat and ultra-processed products(34–36). In fact, studies with adolescent students and adults from capital cities suggest that the frequency of regular consumption of beans (≥ 5 times/week) over the last decade declined mainly among women compared with men (–3·6 % *v.* –2·9 %/year between 2009 and 2015(35) and –1·4 % *v.* –1·2 %/year between 2012 and 2017(36), respectively). In turn, data from the NDS-HBS indicated that decreasing trends between 2008–2009 and 2017–2018 in the frequency of consumption of rice (–9·4 %) and breads (–19·2 %) were especially pronounced among individuals with a family income above two minimum wages per capita (–16·0 % and –28·1 %, respectively)(14,31). Women and individuals from the highest income strata have also consistently scored the lowest adherence to a traditional Brazilian food consumption pattern, characterised by rice, beans and meats(37,38), while also exhibiting the highest percentage of dietary energy shared by ultra-processed foods, such as fast foods and sweets(39). In this context, an overall dilution of dietary Fe as a possible consequence of these dietary pattern combinations has been previously suggested(39,40), owing to the lower Fe content of ultra-processed products in relation to the same energy units of natural or minimally processed foods(40). This phenomenon is in line with the described constancy in the total energy intake estimated in the NDS-HBS 2008–2009 and 2017–2018(30) and with the few variations found in the cumulative contribution of major food sources to the total mineral intake, despite its mean reduction over time.

The specific sex- and income-decreasing trend of Fe intake found in the present study signals relevant challenges for public health policies aimed at combating Fe deficiency in the country. Over the last decades, as in other Latin American countries, profound socio-economic transformations in the food systems of Brazil have evolved in parallel with deteriorating diet quality and an increase in the prevalence of obesity, especially among women(34). While this high-risk group is mainly targeted by the food fortification policy(5), a number of iron-fortified foods include some types of cookies, snacks, packed breads, and ready-to-eat cakes, pastas, and pizzas. These food groups should be avoided in order to control the overweight and obesity epidemics, considering their classification as ultra-processed products(35,41). Instead, consumption of natural food sources of Fe should be encouraged. Notwithstanding, recommended reductions in the high levels of meat consumption in Brazil, in line with the current national dietary guidelines to fight

Table 5. Mean Fe intake (mg/d) and prevalence of inadequate Fe intake (%) among men according to age and Brazilian geographic regions groups in the National Dietary Survey: 2008–2009 and 2017–2018

	2008–2009					2017–2018				
Region and age groups	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI	*n*	Mean	95 % CI	Prevalence of inadequacy	95 % CI
North										
10–13 years	305	11·3	10·8, 11·7	5·3	4·1, 6·5	303	11·4	11·0, 11·8	3·8	2·7, 5·0
14–18 years	301	12·9	12·5, 13·2	8·5	6·2, 10·8	390	12·5	12·2, 12·8	9·6	8·3, 11·0
19–30 years	603	12·9	12·6, 13·1	2·2	1·8, 2·5	686	12·7	12·2, 13·2	2·1	1·6, 2·7
31–50 years	814	12·3	12·1, 12·5	3·1	2·6, 3·5	1126	12·2	11·8, 12·7	2·6	1·7, 3·5
≥ 51 years	462	10·9	10·7, 11·1	6·5	5·5, 7·4	793	10·9	10·5, 11·4	5·7	3·6, 7·7
Northeast										
10–13 years	600	11·3	11·0, 11·7	4·8	3·6, 6·0	568	11·7	11·4, 12·0	3·4	2·7, 4·2
14–18 years	702	12·9	12·4, 13·4	8·4	6·0, 10·9	782	12·8	12·5, 13·1	8·0	6·5, 9·4
19–30 years	1504	12·9	12·6, 13·2	2·1	1·9, 2·4	1423	13·1	12·9, 13·2	1·6	1·3, 2·0
31–50 years	2079	12·3	12·1, 12·4	3·1	2·7, 3·5	2843	12·6	12·4, 12·7	2·2	1·7, 2·7
≥ 51 years	1482	10·9	10·7, 11·1	6·6	5·6, 7·5	2665	11·2	11·2, 11·3	4·7	4·1, 5·3
Southeast										
10–13 years	295	12·5	12·1, 12·8	2·7	1·8, 3·6	319	11·9	11·4, 12·4	2·8	2·1, 3·5
14–18 years	372	14·2	13·8, 14·5	5·0	3·5, 6·5	446	13·0	12·6, 13·4	7·3	6·3, 8·4
19–30 years	699	14·1	14·0, 14·3	1·0	0·9, 1·1	925	13·3	12·8, 13·7	1·4	1·2, 1·6
31–50 years	1332	13·5	13·3, 13·6	1·6	1·3, 1·9	1978	12·8	12·5, 13·1	1·9	1·6, 2·3
≥ 51 years	1032	12·0	11·9, 12·2	3·4	2·9, 3·9	2190	11·4	11·1, 11·8	4·4	3·9, 4·8
Southern										
10–13 years	167	12·4	12·0, 12·8	2·5	1·7, 3·3	150	12·0	11·6, 12·4	2·9	2·2, 3·6
14–18 years	206	14·0	13·6, 14·4	5·1	3·1, 7·0	210	13·1	12·6, 13·6	7·1	5·0, 9·2
19–30 years	435	14·0	13·7, 14·3	1·1	1·0, 1·3	441	13·4	13·0, 13·8	1·3	1·0, 1·7
31–50 years	741	13·4	13·1, 13·6	1·6	1·2, 1·9	1030	12·9	12·4, 13·4	1·8	1·1, 2·5
≥ 51 years	561	11·9	11·8, 12·0	3·8	3·1, 4·5	1215	11·6	11·2, 11·9	3·9	3·1, 4·7
Central-west										
10–13 years	199	11·6	11·1, 12·1	4·2	2·8, 5·6	179	11·8	11·5, 12·1	3·1	2·6, 3·7
14–18 years	230	13·3	12·9, 13·6	7·7	5·8, 9·5	243	12·9	12·7, 13·2	7·5	5·8, 9·1
19–30 years	546	13·2	12·9, 13·5	1·7	1·5, 1·9	483	13·3	13·0, 13·6	1·3	0·9, 1·7
31–50 years	838	12·7	12·4, 12·9	2·4	2·1, 2·8	1005	12·7	12·5, 13·0	1·9	1·4, 2·5
≥ 51 years	544	11·2	11·0, 11·5	5·3	4·3, 6·3	891	11·3	11·1, 11·6	4·7	3·9, 5·4

malnutrition and climate change(41), should have an effect on the population Fe intake and needs to be carefully evaluated, as performed by other studies in different settings(42–44). Besides beans and iron-fortified foods, potential plant-based iron-sourced alternatives to meats include nuts and whole cereals, which lack haem Fe and contain the relatively low bioavailable non-haem iron(4).

According to our findings, the previously described concerns regarding the effectiveness of the mandatory Fe fortification policy seemed to have persisted in Brazil over the last decade. As pointed out by Santos *et al.* (2014), already in 2008–2009, the estimated average consumption of wheat and maize flour by Brazilians (about 80 g/d) was somewhat lower than that planned when designing the Fe fortification programme (100 g/d)(9). Despite our limitation in not directly measuring flour intakes by disaggregating all recipes into ingredients, this scenario did not vary substantially in 2017–2018, considering the relatively constant contribution of the main iron-fortified foods (breads, pasta and pizza, cake and cookies, and fortified maize flour recipes) to the total mineral intake in both studied periods (approximately 40 %). It is worth mentioning that rates of compliance with the minimum recommended Fe fortification level in Brazil have been suggested to be above 80 %, based on flour samples analysed between 2006 and 2019 by a governmental surveillance commission(45,46). With this in mind, another important concern raised is that elemental Fe was mostly employed by Brazilian mills for fortification purposes, despite its low bioavailability(9). In this sense, an update of the fortification programme, with compliance starting in April 2019, has established the obligatory addition of 4 to 9 mg of Fe to each 100 g of wheat and maize flours(47). This update also limits mills to the use of the high bioavailability compounds ferrous sulphate and ferrous fumarate(47).

This study had some limitations. The first is related to changes in the dietary data collection instruments between the two surveys, with FR used in 2008–2009 while 24hR in 2017–2018(16), which could bias Fe inadequacy figures differently. In fact, the recent methodological change was mainly driven by evidence from validation studies pointing to a lower degree of energy underreporting in 24hR than in FR(48). However, a compatibility study concluded that comparison concerns between the two surveys would be mainly regarding data on added sugars and fats(16), which do not directly interfere with the estimates of dietary Fe, as both methods allow us to obtain detailed information on the consumption of the main iron-rich foods and beverages. Another limitation is that our Fe intake estimates did not account for supplement use. Despite being unavailable in the NDS-HBS 2008–2009, the information was assessed in the NDS-HBS 2017–2018, from which it was estimated that 2·4 % of the overall population was using an iron-containing tablet or powder during the preceding 30 d(14). It is noteworthy that pregnant and lactating women, who were excluded from our

Table 6. Relative and cumulative contribution (%) of food groups to Fe intake in Brazil and geographic regions groups. Brazilian National Dietary Survey: 2008–2009 and 2017–2018

	2008–2009			2017–2018		
	Food group	% Relative	% Cumulative	Food group	% Relative	% Cumulative
Brazil						
	Beans	22·1	22·1	Beans	20·6	20·6
	Breads	19·2	41·3	Breads	18·6	39·2
	Red meats	13·3	54·6	Red meats	14·2	53·4
	Pasta and pizza	11·0	65·6	Pasta and pizza	14·2	67·6
	Cakes and cookies	6·8	72·4	Cakes and cookies	6·2	73·8
North						
	Beans	17·8	17·8	Breads	19·6	19·6
	Breads	16·5	34·3	Beans	16·4	36·0
	Red meats	15·4	49·7	Red meats	16·2	52·2
	Pasta and pizza	9·2	58·9	Pasta and pizza	10·1	62·3
	Cakes and cookies	6·2	65·1	Cakes and cookies	5·2	67·5
Northeast						
	Beans	21·7	21·7	Beans	20·6	20·6
	Breads	21·4	43·1	Breads	19·6	40·2
	Red meats	13·1	56·2	Pasta and pizza	12·9	53·1
	Pasta and pizza	7·7	63·9	Red meats	12·4	65·5
	Cakes and cookies	6·8	70·7	Cakes and cookies	6·7	72·2
Southeast						
	Beans	24·6	24·6	Beans	22·6	22·6
	Breads	18·3	42·9	Breads	19·5	42·1
	Red meats	12·4	55·3	Pasta and pizza	14·2	56·3
	Pasta and pizza	11·9	67·2	Red meats	13·7	70·0
	Cakes and cookies	6·7	73·9	Cakes and cookies	5·7	75·7
Southern						
	Breads	20·6	20·6	Pasta and pizza	20·0	20·0
	Beans	16·2	36·8	Breads	16·7	36·7
	Pasta and pizza	15·4	52·2	Beans	15·3	52·0
	Red meats	12·9	65·1	Red meats	14·6	66·6
	Cakes and cookies	7·2	72·3	Cakes and cookies	7·2	73·8
Central-west						
	Beans	24·8	24·8	Beans	23·8	23·8
	Red meats	18·2	43·0	Red meats	20·9	44·7
	Breads	15·5	58·5	Breads	13·2	57·9
	Pasta and pizza	10·2	68·7	Pasta and pizza	11·7	69·6
	Rice	6·2	74·9	Cakes and cookies	6·4	76·0

analysis, accounted for > 75 % of Fe supplement users in the country, possibly reflecting their benefit as the main targeted groups receiving, since 2005, prophylactic ferrous sulphate from the National Iron Supplementation Program (*Programa Nacional de Suplementação de Ferro*)(49).

Owing to the lack of a comprehensive Brazilian food composition database on haem Fe, phytate and iron-binding polyphenols, we could not directly evaluate the dietary Fe bioavailability in our study, which represents another limitation. In addition, considering the current lack of specific Fe requirement distributions or dietary recommendation references for the Brazilian population, we relied on the proposal of the US IOM, as in previous national studies(10–13,24,25). Although we could not guarantee the feasibility of assuming the recommended values, it is worth mentioning that, even in the USA, the IOM's dietary bioavailability factor has been criticised(50). However, a small study including Brazilian women with a similar Fe intake pattern from the general population suggested that assuming North American dietary reference values, based on the estimated bioavailability of a Western-style diet (18 %), might be acceptable in our setting(51). Moreover, against a possible variation in dietary Fe bioavailability over the studied period, which could not be ignored, we observed that red meat, the major dietary source of haem Fe(4), showed quite similar contributions to the total Fe intake of the population in 2008–2009 (about 13 %) and 2017–2018 (about 14 %).

The use of data from the two largest representative surveys of dietary intake in Brazil is one of the major strengths of this study. Different from that performed at the time of the first NDS-HBS, when the North American nutrient database derived from the Nutrition Data System for Research (NDSR) software (University of Minnesota, 2003) aided the assessment of Fe intakes(13), here, we have used genuine national food composition values, dispensing corrections for differences in flour fortification levels between the USA and Brazil, allowing more accurate estimates and precise comparisons(19). Furthermore, rather than assuming a unique Fe requirement distribution from the IOM's proposed alternatives for adolescent and adult menstruating women(4), we used the best quality available data on hormonal contraceptive use from a population-based study performed at the midpoint between the surveys (2013–2014) to weigh dietary Fe inadequacy figures based on the specific prevalence of hormonal contraceptive use in the Brazilian population(22). This approach provides us with more realistic results and allows us to verify nuances of intervention priorities within this greatest risk population group, for example, highlighting women aged 19–31 years with a relatively lower prevalence of Fe intake inadequacy, even with a comparable or higher mean Fe intake than those from other age groups, owing to the high frequency of hormonal contraceptive use (about 50 %)(22).

This study demonstrated that, 4 to 5 and 13 to 14 years after the implementation of the national mandatory Fe fortification programme in Brazil, the prevalence of Fe intake inadequacy remained high in the targeted group of menstruating women. This was especially true for the lowest income stratum, for which figures reaching approximately 40 % were found in both studied periods for prevalence of inadequate Fe intake. Conversely, women from the highest income strata and from the richest Brazilian regions appear to have modified their Fe intake between 2008–2009 and 2017–2008, particularly those in the extremities of the childbearing age range, with the highest reductions observed among adolescent women. We also highlighted that wheat and maize flours were staple foods regularly and widely consumed across the country over the studied periods. This was reflected in iron-fortified foods contributing to approximately 40 % of total mineral intake, exceeding the relevancy of isolated naturally iron-sourced foods, such as beans and red meats. The results suggest a sustained dietary impact of the Fe fortification programme of flour. Despite its impact, long-standing trends suggest that on its own, it is insufficient to correct the concerning prevalence of Fe intake inadequacy among Brazilian menstruating women, irrespective of the country's socio-economic and geopolitical strata and recent changes in population food consumption patterns.

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E. D. C. and D. M. L. M. formulated the research question, designed the study, carried out the study, analysed the data, interpreted the findings and wrote the article. C. Z. P. formulated the research question, designed the study, interpreted the findings and wrote the article. E. V.-J. formulated the research question, designed the study, analysed the data, interpreted the findings and wrote the article. R. S., E. M.Y. and R. A. P. designed the study, carried out the study, interpreted data and wrote the article.

This study was conducted in accordance with the Helsinki Declaration, and all procedures involving research study participants were approved by the ethics committee of the Institute of Social Medicine of State University of Rio de Janeiro (CAAE 37923320·0·0000·5260). All data were obtained from secondary sources and available publicly.

There are no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114523000119

References

1. Camaschella C (2019) Iron deficiency. *Blood* **133**, 30–39.
2. Safiri S, Kolahi A, Noori M, *et al.* (2021) Burden of anemia and its underlying causes in 204 countries and territories, 1990–2019: results from the Global Burden of Disease Study 2019. *J Hematol Oncol* **14**, 185.
3. Murray CJL, Aravkin AY, Zheng P, *et al.* (2020) Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* **396**, 1223–1249.
4. Institute of Medicine & National Academy of Sciences (2001) *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc.* Washington, DC: National Academy Press.
5. Hurrel RF (2022) Ensuring the efficacious iron fortification of foods: a tale of two barriers. *Nutrients* **14**, 1609.
6. Tong H & Walker N (2021) Current levels of coverage of iron and folic acid fortification are insufficient to meet the recommended intake for women of reproductive age in low- and middle-income countries. *J Glob Health* **11**, 18002.
7. Brazil (2002) Brazilian Health Regulatory Agency. *Aprova o Regulamento Técnico para a Fortificação das Farinhas de Trigo e das Farinhas de Milho com Ferro e Ácido Fólico (Approve the Technical Regulations for the Fortification of Wheat Flour and Corn Flour with Iron and Folic Acid).* Diário Oficial da União, Poder Executivo; Brasília. Resolução RDC n° 344. https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/ 2002/rdc0344_13_12_2002.html (accessed June 2022).
8. World Health Organization (2022) Prevalence of Anaemia in Women of Reproductive Age (Aged 15–49) (%). https://www.who.int/data/gho/data/indicators/indicator-details/GHO/prevalence-of-anaemia-in-women-of-reproductive-age-(-) (accessed June 2022).
9. Santos Q, Nilson EAF, Verly Junior E, *et al.* (2015) An evaluation of the effectiveness of the flour iron fortification programme in Brazil. *Public Health Nutr* **18**, 1670–1574.
10. Veiga GV, Costa RS, Araujo MC, *et al.* (2013) Inadequate nutrient intake in Brazilian adolescents. *Rev Saude Publica* **47**, 212S–221S.
11. Araujo MC, Bezerra IN, Barborsa FS, *et al.* (2013) Macronutrient consumption and inadequate micronutrient intake in adults. *Rev Saude Publica* **47**, 177S–189S.
12. Fisberg RM, Marchioni DML, Castro MA, *et al.* (2013) Inadequate nutrient intake among the Brazilian elderly: National Dietary Survey 2008–2009. *Rev Saude Publica* **47**, 222S–230S.
13. Brazilian Institute of Geography and Statistics (IBGE) (2011) Pesquisa de Orçamentos Familiares 2008–2009: Análise do Consumo Alimentar Pessoal no Brasil (Household Budget Surveys 2008–2009: Analysis of personal food intake in Brazil). Rio de Janeiro: IBGE. https://biblioteca.ibge.gov.br/visualizacao/livros/liv50063.pdf (accessed June 2022).
14. Brazilian Institute of Geography and Statistics (IBGE) (2020) Pesquisa de Orçamentos Familiares 2017–2018: Análise do Consumo Alimentar Pessoal no Brasil (Household Budget Surveys 2017–2018: Analysis of personal food intake in Brazil). Rio de Janeiro: IBGE. https://biblioteca.ibge.gov.br/visualizacao/livros/liv101742.pdf (accessed June 2022).
15. Moshfegh AJ, Rhodes DG, Baer DJ, *et al.* (2008) The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. *Am J Clin Nutr* **88**, 324–332.
16. Rodrigues RM, De Carli E, Araujo MC, *et al.* (2021) Limitations in the comparison of the Brazilian National Dietary Surveys of 2008–2009 and 2017–2018. *Rev Saude Publica* **55**, 3s.

17. Brazilian Institute of Geography and Statistics (IBGE) (2011) Pesquisa de Orçamentos Familiares 2008–2009: Tabela de Medidas Referidas para Alimentos Consumidos no Brasil (Household Budget Surveys 2008–2009: Table of Reference Measures for Food Consumed in Brazil). Rio de Janeiro: IBGE. https://biblioteca.ibge.gov.br/visualizacao/livros/liv50000.pdf (accessed June 2022).
18. Universidade de São Paulo (USP) & Food Research Center (FoRC) (2020) Tabela Brasileira de Composição de Alimentos (TBCA). Versão 7.1 (Brazilian Food Composition Table (TBCA). Version 7.1). São Paulo. http://www.fcf.usp.br/tbca (accessed June 2022).
19. Grande F, Giuntini EB, Coelho KS, *et al.* (2019) Elaboration of a standardized dataset for foods fortified with iron and folic acid in Brazil. *J Food Compos Anal* **83**, 103285.
20. Tooze JA, Midthune D, Dodd KW, *et al.* (2006) A new statistical method for estimating the usual intake of episodically consumed foods with application to their distribution. *J Am Diet Assoc* **106**, 1575–1587.
21. Institute of Medicine (US) Subcommittee on Interpretation and Uses of Dietary Reference Intakes & Institute of Medicine (US) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes (2000) *DRI Dietary Reference Intakes: Applications in Dietary Assessment*. Washington, DC: National Academies Press (US).
22. Farias MR, Leite SN, Tavares NUL, *et al.* (2016) Use of and access to oral and injectable contraceptives in Brazil. *Rev Saude Publica* **50**, 14S.
23. Barbosa FS, Sichieri R & Junger WL (2013) Assessing usual dietary intake in complex sample design surveys: the National Dietary Survey. *Rev Saude Publica* **47**, 171S–176S.
24. Block G, Dresser CM, Hartman AM, *et al.* (1985) Nutrient sources in the American diet: quantitative data from the NHANES II survey. I. Vitamins and minerals. *Am J Epidemiol* **122**, 13–26.
25. Vieira DAS, Steluti J, Verly E Jr, *et al.* (2017) Brazilians' experiences with iron fortification: evidence of effectiveness for reducing inadequate iron intakes with fortified flour policy. *Public Health Nutr* **20**, 363–370.
26. Sales CH, Rogero MM, Sarti FM, *et al.* (2021) Prevalence and factors associated with iron deficiency and anemia among residents of urban areas of São Paulo, Brazil. *Nutrients* **13**, 1888.
27. Sadighi J, Nedjat S & Rostami R (2019) Systematic review and meta-analysis of the effect of iron-fortified flour on iron status of populations worldwide. *Public Health Nutr* **22**, 3465–3484.
28. U.S. Department of Agriculture, Agricultural Research Service Food Surveys Research Group. What We Eat in America Data Tables, NHANES 2017–2018 (Last Modified: 8 March 2022). https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/wweia-data-tables/ (accessed June 2022).
29. Food and Drug Administration (FDA) (1980) Nutritional quality of foods; addition of nutrients. Final policy statement. *Fed Regist* **45**, 6314–6324.
30. Verly Junior E, Marchioni DM, Araujo MC, *et al.* (2021) Evolution of energy and nutrient intake in Brazil between 2008–2009 and 2017–2018. *Rev Saude Publica* **55**, 5s.
31. Rodrigues RM, Souza AM, Bezerra IN, *et al.* (2021) Most consumed foods in Brazil: evolution between 2008–2009 and 2017–2018. *Rev Saude Publica* **55**, 4s.
32. Brazilian Institute of Geography and Statistics (IBGE) (2020) Pesquisa de Orçamentos Familiares 2017–2018: Análise da segurança alimentar no Brasil (Household Budget Surveys 2017–2018: Analysis of Food Security in Brazil). Rio de Janeiro: IBGE. https://biblioteca.ibge.gov.br/visualizacao/livros/liv101749.pdf (accessed June 2022).
33. Kubo SEAC, Costa THM & Gubert MB (2020) Intakes of energy, macronutrients and micronutrients of a population in severe food insecurity risk in Brazil. *Public Health Nutr* **23**, 649–659.
34. Popkin BM & Reardon T (2018) Obesity and the food system transformation in Latin America. *Obes Rev* **19**, 1028–1064.
35. Gonçalves HVB, Canella DS & Bandoni DH (2020) Temporal variation in food consumption of Brazilian adolescents (2009–2015). *PLoS One* **15**, e0239217.
36. Granado FS, Maia EG, Mendes LL, *et al.* (2020) Reduction of traditional food consumption in Brazilian diet: trends and forecasting of bean consumption (2007–2030). *Public Health Nutr* **24**, 1185–1192.
37. Antunes ABS, Cunha DB, Baltar VT, *et al.* (2021) Dietary patterns of Brazilian adults in 2008–2009 and 2017–2018. *Rev Saude Publica* **55**, 8s.
38. Andrade GC, Louzada MLC, Azeredo CM, *et al.* (2018) Out-of-home food consumers in Brazil: what do they eat? *Nutrients* **10**, 218.
39. Louzada MLC, Baraldi LG, Steele EM, *et al.* (2015) Consumption of ultra-processed foods and obesity in Brazilian adolescents and adults. *Prev Med* **81**, 9–15.
40. Louzada MLC, Martins APB, Canella DS, *et al.* (2015) Impact of ultra-processed foods on micronutrient content in the Brazilian diet. *Rev Saude Publica* **49**, 45.
41. Brazil (2014) Ministry of Health of Brazil. Secretariat of Health Care. Primary Health Care Department. Dietary Guidelines for the Brazilian population https://bvsms.saude.gov.br/bvs/publicacoes/dietary_guidelines_brazilian_population.pdf (accessed June 2022).
42. Farsi DN, Uthumange D, Munoz JM, *et al.* (2021) The nutritional impact of replacing dietary meat with meat alternatives in the UK: a modelling analysis using nationally representative data. *Br J Nutr* (Epublication ahead of print version 21 July 2021).
43. Salomé M, Huneau JF, Baron C, *et al.* (2021) Substituting meat or dairy products with plant-based substitutes has small and heterogeneous effects on diet quality and nutrient security: a simulation study in French adults (INCA3). *J Nutr* **151**, 2435–2445.
44. Vatanparast H, Islam N, Shafiee M, *et al.* (2020) Increasing plant-based meat alternatives and decreasing red and processed meat in the diet differentially affect the diet quality and nutrient intakes of Canadians. *Nutrients* **12**, 2034.
45. Brazil (2011) Ministry of Health of Brazil. II Reunião Ordinária da Comissão Interinstitucional para Implementação, Acompanhamento e Monitoramento das Ações de Fortificação de Farinhas de Trigo, Milho e de seus Subprodutos. (II Ordinary Meeting of the Interinstitutional Commission for the Implementation, Accompaniment and Monitoring of Actions for the Fortification of Wheat Flours, Corn and Their Subproducts). http://189.28.128.100/dab/docs/portaldab/documentos/2_reuniao_ordinaria.pdf (accessed October 2022).
46. Brazil (2020) Brazilian Health Regulatory Agency. Relatório do Monitoramento da Fortificação de Farinhas de Trigo e Milho com Ferro e Ácido Fólico (Monitoring Report on Wheat and Corn Flour Fortification with Iron and Folic Acid). https://www.gov.br/anvisa/pt-br/centraisdeconteudo/publicacoes/monitoramento/programas-nacionais-de-monitoramento-de-

alimentos/RelatrioFortificaodeFarinhas2019.pdf (accessed October 2022).

47. Brazil (2017) Brazilian Health Regulatory Agency. *Dispõe sobre o enriquecimento das farinhas de trigo e de milho com ferro e ácido fólico (Disposes about the Fortification of Wheat Flour and Corn Flour with Iron and Folic Acid).* Diário Oficial da União, Poder Executivo; Brasília. Resolução RDC nº 150. https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2017/rdc0150_19_04_2017.pdf (accessed June 2022).

48. Lopes TS, Luiz RR, Hoffman DJ, *et al.* (2016) Misreport of energy intake assessed with food records and 24-h recalls compared with total energy expenditure estimated with DLW (published correction appears in *Eur J Clin Nutr* 2017 71:680). *Eur J Clin Nutr* **70**, 1259–1264.

49. Brazil (2005) Ministry of Health of Brazil. Manual Operacional: Programa Nacional de Suplementação de Ferro (Operational Manual of the National Iron Supplementation Program). Brasília: Ministério da Saúde. https://bvsms.saude.gov.br/bvs/publicacoes/manual_suplementacao_ferro_condutas_gerais.pdf (accessed June 2022).

50. Armah SM, Carriquiry AL & Reddy MB (2015) Total iron bioavailability from the US diet is lower than the current estimate. *J Nutr* **145**, 2617–2621.

51. De Carli E, Dias GC, Morimoto JM, *et al.* (2018) Dietary iron bioavailability: agreement between estimation methods and association with serum ferritin concentrations in women of childbearing age. *Nutrients* **10**, 650.