Applied Food Research 5 (2025) 100947

Contents lists available at ScienceDirect

Applied Food Research

journal homepage: www.elsevier.com/locate/afres

Nutritional characterization of foods fortified with micronutrients in the Spanish market. The BADALI project

Marta Rodríguez [a], Marta Beltrá [b], Fernando Borrás [c], Ana B. Ropero [b,*]

[a] Polytechnic School of Orihuela, Miguel Hernández Univer sity, 03312 Orihuela, Spain
[b] Institute of Bioengineering, Miguel Hernández University, 03202 Elche, Spain
[c] Department of Statistics, Mathematics and Informatics, Miguel Hernández University, 03202 Elche, Spain

ARTICLE INFO

Keywords:
Fortification
Micronutrients
Food database
Nutrient composition
Nutrition claims

ABSTRACT

Although fortified foods may reduce micronutrient deficiencies, they may contain nutrients negatively associated to health. The aim of this work is to provide a comprehensive study of micronutrient fortified processed foods available in Spain and to compare them with unfortified foods. For this purpose, 4313 items were analysed belonging to 12 food types and 16.6 % of them were fortified with micronutrients. Fruit drinks and milk substitutes had the highest prevalence (42.9 % and 36.3 % respectively) and vitamin D and calcium were the micronutrients most frequently added (8.3 % and 7.1 % respectively). Fortified foods used nutrition claims more often than the unfortified version (78.2 % vs 43.6 %), most of them about micronutrients (74 % vs 3.9 %). Both nutritional improvements and deteriorations in the nutrient composition were observed in fortified foods compared to the unfortified version. Regarding the nutritional quality, 83.7 % of fortified and 80.8 % of unfortified foods were classified as "less healthy". Fortified foods presented less items high in total and saturated fat (40 % and 49 % less), while more in free sugar, sodium and more had sweeteners (15 %, 22 % and 66 % more). Therefore, this work shows that most fortified foods cannot be considered healthy and that they are not nutritionally better than the unfortified version.

1. Introduction

Vitamins and minerals are nutrients needed by the body in very small amounts and they are critical for healthy development, disease prevention and wellbeing (WHO, n.d.; CDC, 2023). Given their vital role in biological processes, deficiencies in micronutrients can cause severe and even life-threatening conditions (WHO, n.d.). They can also induce "less clinically notable reductions in energy level, mental clarity and overall capacity" (WHO, n.d.). Micronutrient insufficiencies are not exclusive of low-income countries. Variable deficiencies and suboptimal intakes have been reported for several micronutrients in high-income countries, including Spain (Gulyas et al., 2024; Han et al., 2022;Olza et al., 2017a; Partearroyo et al., 2017). Of these, vitamin D is of particular concern in Western countries (Amrein et al., 2020; Gulyas et al., 2024; Olza et al., 2017a).

Food fortification with micronutrients may be useful to prevent these deficiencies, following mandatory, voluntary or limited fortification policies (Bird et al., 2022; Das et al., 2019; de Jong et al., 2022b; Newman et al., 2019; Tarasuk & Brassard, 2021). A review published in 2019 analysed 127 studies, most of them conducted in children, and concluded that multiple micronutrient fortification may reduce anaemia and deficiency of several vitamins and minerals by 32–91 % (low-quality evidence) (Das et al., 2019). The results of the NHANES 2009–2012 study in the USA showed that food fortification reduced the percentage of the population with intakes below the estimated average requirement for many vitamins and iron (Newman et al., 2019). A more recent study conducted in Canada reported that consumers of voluntarily fortified foods had median intakes 24–111 % higher than non-consumers on several vitamins and zinc, which led to a lower prevalence of inadequacy for some of the vitamins analysed (Tarasuk & Brassard, 2021). A 2022

Abbreviations: AESAN, Spanish Agency for Food Safety and Nutrition; ANIBES, Study of Anthropometry, Intake, and Energy Balance in Spain; ANOVA, Analysis of Variance; BADALI, Food Database; BEDCA, Spanish Food Composition Database; CAGR, Compound Annual Growth Rate; EFSA, European Food Safety Authority; IR, interquartile range; min, minerals; LNCS, low- or no-calorie sweeteners; NCs, nutrition claims; PAHO—NPM, Pan American Health Organization/World Health Organization – Regional Office in Iberoamerica Nutrient Profile Model; vit, vitamins; WHO, World Health Organization.

* Corresponding author at: Institute of Bioengineering, Miguel Hernández University, 03202 Elche, Spain.
E-mail address: ropero@umh.es (A.B. Ropero).

https://doi.org/10.1016/j.afres.2025.100947
Received 15 October 2024; Received in revised form 22 April 2025; Accepted 3 May 2025
Available online 3 May 2025

study in Netherlands showed that users of voluntary fortified foods "had up to 64 % higher habitual micronutrient intakes, compared to non-users" (de Jong et al., 2022b). Another in the UK, published in 2022, showed that "about 3–13 % fewer consumers of fortified foods fell below the estimated average recommendations for vitamins and minerals" (Bird et al., 2022). However, other reports have shown little or no difference on micronutrient intake (Hombali et al., 2019; Peña-Rosas et al., 2019).

The fortified food market is a profitable business globally, also in Spain, and Asia, Europe and America are leading the market (Pistorio et al., 2023). It grew at a Compound Annual Growth Rate (CAGR) of 2.5 % between 2018 and 2022 (Future Market Insights, 2024a). The market is projected to grow at a CAGR of 6.2 – 10.2 % from 2023 to 2033, while the vitamin segment is anticipated to grow even further (Precedence Research, 2023; Future Market Insights, 2024a). The micronutrient market is not exclusive to low- and middle-income countries. In fact, the European food fortification market share was 31 % in 2022 and is forecast to grow at a CAGR of 2.9 % between 2020 and 2025 (Precedence Research, 2023; Glanbia Nutritionals, 2022). B and C vitamins are the most commonly added fortifying ingredient in new product launches in Europe (Glanbia Nutritionals, 2022).

Studies reporting on the actual use of micronutrient fortified/enriched foods in high-income countries are limited and depend heavily on the country's fortification policy. A recent study in Canada showed that only 2.4 % of the population aged one year and older reported consumption of voluntarily fortified foods (Tarasuk & Brassard, 2021). However, the rate was as high as 75 % in Netherlands (de Jong et al., 2022b). In Spain there is no mandatory fortification policy in force and the only recent data on the intake of fortified foods is on milk, which decreased from 2019 (10.77 L/person) to 2022 (8.39 L/person), with a slight increase in 2023 (8.73 L/person) (MAPA, 2024).

What is the actual rate of micronutrient fortification in commercially available foods? Several papers have been published so far in Ireland, Slovenia, Portugal, Japan and Spain on this subject (Egan et al., 2019; Krusic et al., 2022; Martins et al., 2022; Nishijima et al., 2023; Samaniego-Vaesken et al., 2016; Samaniego-Vaesken et al., 2017a). The Irish and the Spanish publications studied food fortification only with folic acid, while the one in Slovenia was limited to vitamin D (Egan et al., 2019; Krusic et al. 2022; Samaniego-Vaesken et al., 2016; Samaniego-Vaesken et al., 2017a). The works conducted in Portugal and Japan analysed fortification with the full range of micronutrients (Martins et al., 2022; Nishijima et al., 2023). The Japanish study analysed a small sample of 907 foods classified in very heterogeneous food types (Nishijima et al., 2023). The Portuguese study was limited to analysing fortified foods consumed by participants in the National Survey (IAN-AF 2015–16), rather than those commercially available (Martins et al., 2022). Therefore, the present work is the only one anywhere in the world to carry out a comprehensive study of food fortification of large samples of specific food types with the full range of micronutrients.

Consumer attitudes towards fortification are generally favourable and may increase food acceptance (Chinnici et al., 2023; Clark et al., 2019; Masson et al., 2016). It has been reported that nutritional properties is the second most important driver for the consumption of fortified foods (Chinnici et al., 2023). In addition, "I consider it beneficial to eat fortified foods" and "regular intake of fortified foods can prevent illnesses caused by unhealthy diets" were shown to be the main motivations (Chinnici et al., 2023). Specifically for micronutrient fortified foods or supplements, the main reasons reported were the maintenance of health, supplementation of nutrients, prevention of diseases and beauty benefits (Chiba et al., 2021; Chiba et al., 2022). A work in the US with snacks concluded that vitamin fortification may result in a higher probability of selecting the food for purchase and more likely to perceive it as healthier (Verril et al., 2017). According to a systematic review, yogurts with added calcium are one of the most valued dairy products, particularly among female consumers (Bimbo et al., 2017). Another publication reported that many Chinese consumers believed that the consumption of nutritionally fortified eggs is healthy (Tian et al., 2022). Furthermore, consumers who pay close attention to the nutritional value of foods may be likely to pay more for fortified foods (Castellini et al., 2022; Reitano et al., 2024).

The impact of fortification on food choice may be reinforced by the use of nutrition claims (NCs), which increase the perceived healthfulness of these foods (Iles et al., 2017). The use of NCs has been studied for some decades and they generally raise the perceived nutritional quality and healthiness of foods as well as influence purchasing behaviour (Ballco & Gracia, 2022; Rramani et al., 2023). However, the presence of NCs can affect food choices in a more complex and risky way, such as reducing the probability of understanding information about food composition (Senna et al., 2022). In fact, a work in US showed that snack foods carrying nutrient claims for vitamin fortification affected some of consumers' decisions. They were less likely to look for information on the nutrition facts label and were less likely to correctly choose the healthiest products (Verril et al., 2017).

These evidence show that the market for micronutrient fortified foods is on the rise and that consumers perceive them as healthy or healthier than unfortified foods, particularly when they carry nutrition claims. Are consumers' perceptions right? Are micronutrient fortified foods healthy or healthier than the unfortified version? These questions are of paramount importance for public health and, to our knowledge, no publication has ever produced an answer.

Therefore, the aim of this work was to carry out a comprehensive study of the micronutrient fortification of large samples of specific food types commercially available in Spain. In addition, the nutrient composition and nutritional quality of these foods were analysed. A comparison with unfortified foods was also carried out and the use of nutrition claims to attract the attention of consumers was evaluated.

2. Material and methods

2.1. BADALI database of foods available in the Spanish market

There is no free database of foods commercially available in Spain for research purposes. Therefore, the authors developed the Food Database, BADALI, at Miguel Hernández University and made it available online in November 2016 (BADALI, n.d.; Ropero et al., 2017; Ropero et al., 2023). Initially, BADALI was intended exclusively for educational purposes and to help the general population choose the best foods for a healthy diet. However, it later became a research project. The information in the database has been updated over the years.

The data comes from manufacturers' and supermarkets' webpages and most foods are processed (Ropero et al., 2023). The inclusion criteria are: (1) foods sold in any Spanish supermarket; and (2) foods with the nutrition declaration (Ropero et al., 2023). The information is extracted, reviewed by the researchers, and inconsistent data is removed from the database. Duplicates and foods with different pack sizes are also removed. At present, >10,400 foods commercially available in Spain are included in BADALI. The nutrition declaration, some ingredients and an adapted version of the Chilean front-of-pack labelling are available online for each food in the database (BADALI, n.d.; Ministerio de Salud, 2015). More information is collected for internal use as the project progresses. For the present study, data was collected from June 2022 to March 2024 and the presence of added vitamins or minerals and nutrition claims were recorded as described in Sections 2.2. and 2.4.

2.2. Fortification with vitamins and minerals

Fortification was determined according to the ingredient declaration available. Foods with no ingredient list were discarded. As previously described, a product was classified as fortified with vitamins or minerals when: (1) a chemical providing a vitamin or mineral was listed as an ingredient, and (2) no indication of an additive function for this chemical was provided (Ropero et al., 2023). When the same compound was source of two minerals, it was acknowledged that the product was fortified with both. As an example, when potassium iodine was added, it was listed as fortified with both potassium and iodine. The algae *Lithothamnium calcareum* was registered as a means of calcium fortification. Fortification was not considered to be present when salt was included in the ingredient declaration as "sodium chloride".

2.3. Nutrient composition analysis

The data on the nutrition declaration of each food available in the manufacturers' or supermarkets' webpages was transferred to the database and used to analyse the nutrient composition of foods. This analysis was conducted as previously reported (Ropero et al., 2023). Statistics were applied to determine significant differences in nutrient composition between micronutrient fortified and unfortified foods (see Section 2.6). However, only divergences of at least 30 % in median values were considered nutritionally relevant as previously published (Ropero et al., 2023). This criterion was based on the definitions of the nutrition claims "reduced" and "increased" included in the European Regulation 1924/2006 (European Parliament, 2006). To claim reduced content in sodium/salt, 25 % decrease was required (European Parliament, 2006).

2.4. Evaluation of the nutritional quality of foods

The Nutrient Profile Model developed by the Pan American Health Organization/World Health Organization and the Regional Office in Iberoamerica (PAHO—NPM) was used to assess the nutritional quality of foods as previously reported (PAHO, 2016; Beltrá et al., 2020; Ropero et al., 2023). The PAHO—NPM classifies foods as "high in" any of the following critical nutrients: sodium, free sugar, total fat, saturated fat, trans fat and the presence of any low- or no-calorie sweeteners (LNCS) (PAHO, 2016). Foods were considered to be "high in" any critical nutrient when their content exceeded the following thresholds: (1) $\geq$1 mg sodium/kcal; (2) $\geq$10 % of total energy from free sugars; (3) $\geq$30 % of total energy from total fat; and (4) $\geq$10 % of total energy from saturated fat (PAHO, 2016). In the present study, we applied these criteria to each food and provided the number and percentage of items exceeding any of the thresholds, as well as those having LNCS. The criterion for trans-fat could not be applied because none of the products provided the content.

The ingredient list was checked for low- or no-calorie sweeteners (LNCS), i.e. foods were considered to contain LNCS if the word "sweetener" was displayed next to the name of the LNCS (PAHO, 2016). The PAHO—NPM does not discriminate between polyols (low-calorie) and no-calorie sweeteners. Hence, they were both listed as sweeteners in this work, except when polyols were acting as humectant, stabilizer or any additive function other than sweeteners (as indicated in the ingredient list) (PAHO, 2016). The PAHO—NPM was not intended to be applied to foods without added fat, salt, sweeteners or free sugar. Therefore, they were included in the study as not exceeding any of the thresholds.

Estimation of free sugar was carried out following Swan et al., 2018 and described in detail here: (1) all sugars present in milk/yogurt/dairy dessert substitutes and fruit drinks were considered free, except for those from milk added as an ingredient (Swan et al., 2018; WHO, 2015); (2) cereal products (cereal bars, biscuits, breakfast cereals) without added sugar have no free sugar; (3) 2 g sugar/100 g was subtracted from total sugar in biscuits, cereal bars and breakfast cereals because this is the natural sugar content in the most commonly used grains (BEDCA, 2006); (4) 5 g sugar/100 g was subtracted from the total sugar content in milk/dairy drinks and yogurts/fermented milk because this is the natural lactose maximum content in milk (BEDCA, 2006); (5) free sugar in plant-based meat analogues was estimated according to the list of ingredients; (6) sugar in nuts added as ingredients was not considered free, whatever the process, except drinks included in point (1); (7) sugar in fruit and dry fruit was considered free when added in puree or paste (bars, yogurts); (8) although sugar content of some products was not available, free sugars could be estimated based on the list of ingredients. Free sugar content of some bars was impossible to estimate because the proportion of dry fruit in paste, puree or any other form was not provided. Therefore, their nutritional quality could not be determined and they were excluded from this analysis.

Foods with no added fat, salt, sweeteners or free sugars were classified as "healthy", as well as those that did not exceed any of the thresholds for critical nutrients or had no LNCS (PAHO, 2016). Foods were considered "less healthy" when they exceeded the threshold for any of the critical nutrients or had LNCS (PAHO, 2016). Only foods with data for all five components (sodium/salt, sugar, total fat, saturated fat, LNCS) were included in the global statistics for "less healthy".

2.5. Nutrition claims (NCs) analysis

Nutrition claims (NCs) were analysed as previously described and following Regulation (EC) No 1924/2006 (European Parliament, 2006; Ropero et al., 2023). The websites of most manufactures or supermarkets provide only an image of the product, usually the front of the package. Some webpages also provide images of the back or sides of the package. In order to avoid any bias, only the main image of the food was used, and when more than one was available, the image of the front of the package was used. Foods with unreadable images were not used for this analysis.

NCs displayed as pictorial, graphic or symbolic representations are also included in the European Regulation (EC) No 1924/2006 (European Parliament, 2006). However, they were not subject to the analysis in the present work because they are open to interpretations (European Parliament, 2006). Therefore, only NCs displayed as text were analysed. Authorized NCs are listed in the Annex of Regulation (EC) No 1924/2006 (European Parliament, 2006). However, manufacturers also use other unauthorized NCs. Both were analysed in the present study.

NCs associated with health claims were also listed, such as "this food contains iron which contributes to…". General NCs, such as "with minerals/vitamins", were considered as many as the number of micronutrients included in the nutrition declaration, e.g. if the content of 7 micronutrients was shown in the nutrition declaration, 7 NCs were recorded. However, if no micronutrient was displayed in the nutrition declaration, the NC was registered as one. Sentences such as "15 % dairy vitamin D" were not listed as NCs, because they are repetition of the data in the nutrition declaration. The mere mention of a nutrient was considered as NC due to the definition of 'nutrition claim' included in the European Regulation (European Parliament, 2006).

NCs authorized by the European Regulation were classified into categories according to the claimed component: fat, fibre, light, minerals, protein, sodium/salt, sugar and vitamins (European Parliament, 2006). Other authorized NCs and those unauthorized were included in "other". Some examples of NCs in this category are: with leucine, energy, BCAA, with less added sugar, zero, with DHA, etc.

2.6. Statistics

Comparative analyses between fortified and unfortified foods were conducted exclusively for food categories with a minimum sample size of 30 items per condition, including comparisons involving the aggregate sample. The Kruskal-Wallis H test, alternatively referred to as the one-way ANOVA on ranks, was employed as a rank-based nonparametric method to assess statistically significant differences among two or more food groups of an independent variable on a continuous or ordinal dependent variable. While this nonparametric ANOVA does not assume normality of random error distribution, it necessitates independence of random errors. To evaluate whether data distributions across different columns or rows in contingency tables originated from the same population, the chi-square test of homogeneity was utilized, determining if observed differences could be attributed to sampling error alone. For all statistical analyses, the significance threshold was established at $p < 0.05$.

Statistical analysis of the application data was performed using Microsoft Excel and Google Colab with Jupyter Notebooks. The following software libraries were employed: scikit-learn (version 0.22.2. post1), Pandas (version 0.25.3), and Matplotlib Python (version 3.2.0).

3. Results

3.1. Description of the sample and prevalence of micronutrient fortification

A total of 4313 processed foods were included in the present study, belonging to 12 specific food types (Tables 1 and S1). Globally, at least one vitamin or mineral was added to 16.6 % of foods (Table 1). Fortification with vitamins was slightly higher than with minerals (13.8 % vs 10 %), while 7.2 % had both (Table 1).

Fortification was heterogeneous across food types (Table 1). No toasted bread or cereal cakes/crackers were fortified. On the contrary, as many as 42.9 % fruit drinks had added micronutrients, mainly vitamin C (98 of 108 fortified) (Tables 1 and S2). Milk substitutes followed with a fortification rate of 36.3 %, all but one with calcium and 78 of 122 with vitamin D (Tables 1 and S2). Milk/dairy drinks had also a high prevalence (30.6 %), with vitamins D, A and E as the leading micronutrients (115, 97 and 82 of 124 fortified respectively) (Tables 1 and S2).

Calcium was the most frequently added mineral (7.1 %), followed by iron (3.7 %) and phosphorus (2.9 %) (Fig. 1A). Phosphorus fortification may be unintentional for the most part because calcium, magnesium and iron are often added as phosphate salt. Vitamin fortification showed more diversity (Fig. 1B). Vitamin D had the highest prevalence (8.3 %), followed by vitamin B6 (5.3 %), E (5.1 %), A and B9/folic acid (5 % each) (Fig. 1B).

It is interesting to note that all 35 fortified yogurt/dairy dessert substitutes had added calcium (Tables S2). Cereal products (bars, biscuits and breakfast cereals) were predominantly fortified with vitamin B. Calcium and iron were the main minerals added to biscuits. Vitamin B12 was the most frequently added micronutrient to plant-based meat analogues followed by iron (27 and 20 of 30 respectively). The complete description of micronutrients added by food type is shown in table S2.

According to our data, food is usually fortified with more than one micronutrient. Only 25.5 % of foods presented one added micronutrient in the present study, while 40.5 % had two to four (Fig. 1C).

3.2. Nutrition claims

We then analysed the use of nutrition claims (NCs) to attract consumers' attention. Foods with added minerals/vitamins had a higher prevalence of NCs than non-fortified ones (78.4 % vs 43.6 % respectively) (Fig. 2A). In fact, fortified foods presented a rate of 2.6 NCs/food vs 0.6 for unfortified (Fig. 2B). A higher use of NCs in fortified foods was observed in six of the nine food types, while only yogurt/dairy dessert substitutes presented more NCs in the unfortified version (Fig. 2A).

When nutrients used in the NCs were analysed, 73.9 % of them referred to minerals/vitamins among fortified foods (15.5 % and 58.4 % respectively), while only 3.9 % among unfortified (2.9 % for minerals and 1 % for vitamins) (Fig. 2C). In fact, as many as 56.5 % fortified foods made NCs about micronutrients, while only 2.2 % unfortified (Fig. 2D). In order, sugar, fibre and protein were the nutrients most frequently claimed among unfortified foods (Fig. 2C).

3.3. Nutrient composition analysis

Our next step was to analyse the nutrient composition of fortified foods (Table 2). Since fortification may increase the acceptance of these foods, the comparison with unfortified items is crucial. A large number of statistically significant differences were obtained, although only one-third-of them were considered nutritionally relevant (see Material and methods) (Table 2). Some of these differences may be regarded as positive, such as the increase in protein content in fortified yogurt/dairy dessert substitutes (95 % more) or the 34 % decrease in total fat. The main reason for the higher protein content may be that soy was the main component of 34 of the 35 fortified (97.1 %), while only 38.7 % of the unfortified yogurt/dairy dessert substitutes (41 of 106).

Other positive outcomes were the lower values in saturated fat and sugar obtained in fortified biscuits (57 %) and milk substitutes (33 %) respectively. It is interesting to note that yogurts/fermented milk with added micronutrients presented lower total and saturated fat content (39 % and 50 % less respectively). This may be due to the use of milk with less fat. In addition, fortified breakfast cereals contained 48 % less total fat. The 56 % decrease in sugar content in plant-based meat analogues with added micronutrients may be considered unimportant because both median values were low (0.8 g and 1.8 g).

The negative results obtained were striking. Fortified bars contained more than double sodium than the unfortified version. In addition, breakfast cereals with added micronutrients presented 76 % more sugar as well as nine times more sodium. The main reason may be that breakfast cereals with no added ingredients were mostly unfortified (97 of the 98 included in the study). These have low sugar and sodium content (BEDCA, 2006). When breakfast cereals with added ingredients were compared, fortified items still had a higher sugar content (29 % more), but the differences were smaller (76 % more sugar for the total sample) (Tables 2 and S3).

Carbohydrates values were lower for fortified milk substitutes and

Table 1
Items included in the study and fortification with minerals and/or vitamins.

Food Types	No Foods				
	Total	With added vit OR min (%)	With added vit (%)	With added min (%)	With added vit AND min (%)
Bars	268	60 (22.4)	52 (19.4)	35 (13.1)	27 (10.1)
Biscuits	641	63 (9.8)	60 (9.4)	45 (7)	42 (6.6)
Bread	351	22 (6.3)	6 (1.7)	20 (5.7)	4 (1.1)
Breakfast cereals	424	76 (17.9)	71 (16.7)	67 (15.8)	62 (14.6)
Cereal cakes/crackers	181	0 (0)	0 (0)	0 (0)	0 (0)
Fruit drinks	252	108 (42.9)	105 (41.7)	5 (2)	2 (0.8)
Milk/dairy drinks	405	124 (30.6)	117 (28.9)	53 (13.1)	46 (11.4)
Milk substitutes	336	122 (36.3)	79 (23.5)	121 (36)	78 (23.2)
Plant-based meat analogues	282	30 (10.6)	28 (9.9)	22 (7.8)	20 (7.1)
Toasted bread and similar	225	0 (0)	0 (0)	0 (0)	0 (0)
Yogurt/dairy dessert substitutes	141	35 (24.8)	13 (9.2)	35 (24.8)	13 (9.2)
Yogurts/fermented milk	807	77 (9.5)	65 (8.1)	28 (3.5)	16 (2)
TOTAL	4313	717 (16.6)*	596 (13.8)*	431 (10)*	310 (7.2)*

* Percentage of the total food sample. vit: vitamins. min: minerals. %: Percentage of the total food sample by food type.

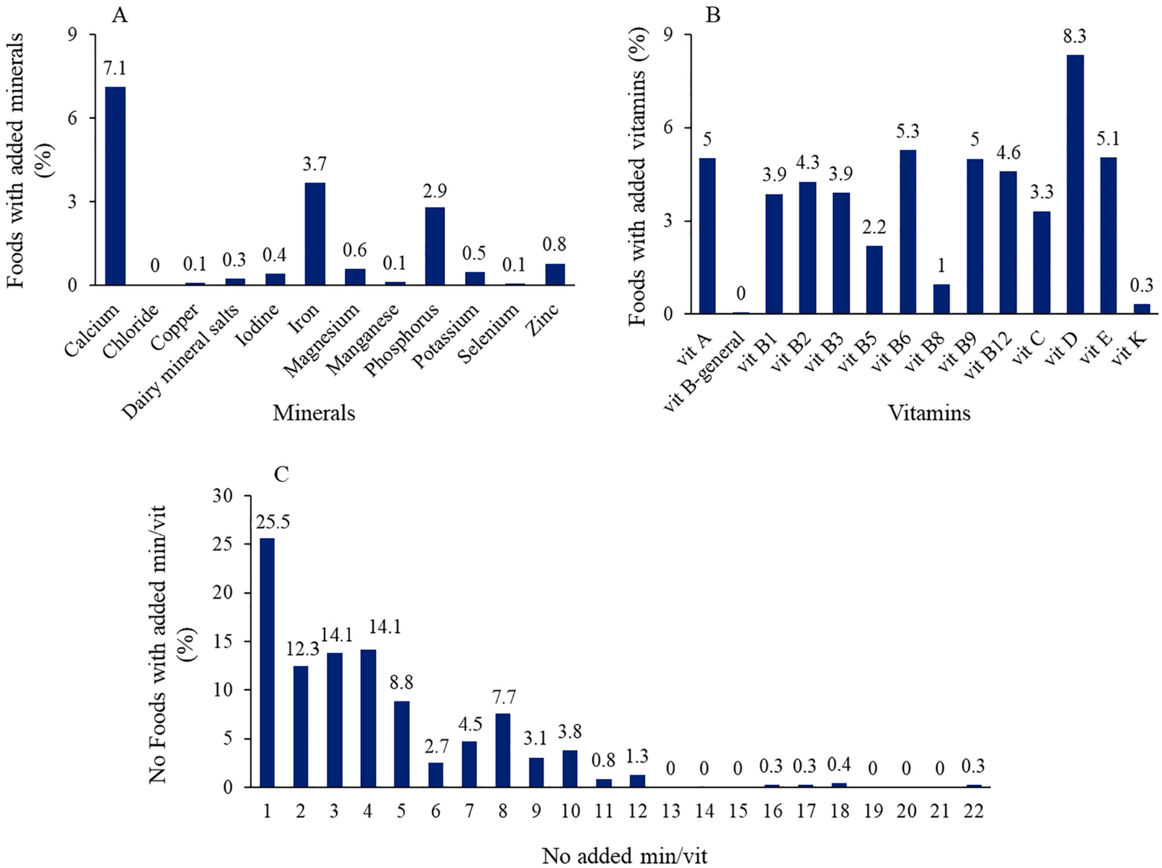

Fig. 1. Characterization of micronutrient fortification. Frequency of mineral (A) and vitamin (B) fortification, by micronutrient. (C) Frequency of fortification by number of micronutrients added. Min/vit: minerals or vitamins. Three biscuits were excluded from (C) because the specific vitamins and/or minerals added were not indicated in the ingredient list. Vit B-general in (B): 2 items of 4313 = 0.05 %.

plant-based meat analogues (36 % and 55 % respectively), which cannot be explained solely by the decrease in sugar content. Finally, no nutritionally relevant differences were observed in milk/dairy and fruit drinks.

3.4. Evaluation of food "Healthiness"

We next analysed the nutritional quality of foods by applying the Pan American Health Organization/World Health Organization-Regional Office in Iberoamerica Nutrient Profile Model (PAHO—NPM) (Table 3). As many as 83.7 % fortified foods were classified as "less healthy" and 66.9 % were high in free sugar. In addition, around one in four items were high in fat (26.8 %) or high in sodium (22.7 %), while one in five were high in saturated fat (18.9 %) or had sweeteners (19.4 %).

When both categories were compared, there was no difference in the proportion of foods considered "less healthy" (83.7 % in fortified, 80.7 % in unfortified) (Table 3). However, more fortified breakfast cereals and yogurts/fermented milk were "less healthy" compared to the unfortified version (63 % and 19 % more respectively).

For the total sample, all nutrients exhibited divergences (Table 3). More fortified items were high in free sugar, sodium and had sweeteners, while less were high in total and saturated fat. The highest percentage of products with sweeteners in the fortified category was driven primarily by yogurts/fermented milk, fruit and milk/dairy drinks. On the contrary, less use of sweeteners was registered in fortified biscuits. The proportion of items high in free sugar was only different in breakfast cereals, which was higher for those with added micronutrients, as expected according to the data on total sugar (Tables 2 and 3).

Results on total and saturated fat were more homogeneous (Table 3). Less fortified foods were considered high in fat in five food types and more in two (milk/dairy drinks and milk substitutes). As for saturated fat, all three food types showing differences had lower proportion of items high in saturated fat for the fortified version. Three food types showed more items high in sodium for the fortified version (breakfast cereals, milk and yogurt/dairy dessert substitutes).

4. Discussion

In the present work, a comprehensive study of the fortification of 4313 foods belonging to twelve food types was carried out. Fruit drinks, milk substitutes and milk/dairy drinks had the highest fortification rate, while vitamin D and calcium were the most frequently added micronutrients. The current results show that fortified foods use nutrition claims (NCs) more frequently and most of them are about minerals or vitamins. The nutrient composition and nutritional quality of fortified foods were also described and compared to the unfortified version. Mix results were obtained, some showing improvements in fortified foods, while others reflected deterioration in their nutritional quality. Importantly, more than four in five fortified foods were classified as "less healthy". Therefore, we cannot conclude that fortified foods are healthy or that they are nutritionally better than the unfortified version.

4.1. Food fortification in Spain and other countries

Only two previous studies on fortification in Spain have been published, both with folic acid, and the information was collected from 2007 to 2015 (Samaniego-Vaesken et al. 2016; Samaniego-Vaesken et al. 2017a). The analysis conducted only applied to fortified foods and, as a consequence, the prevalence was not analysed nor the nutrient

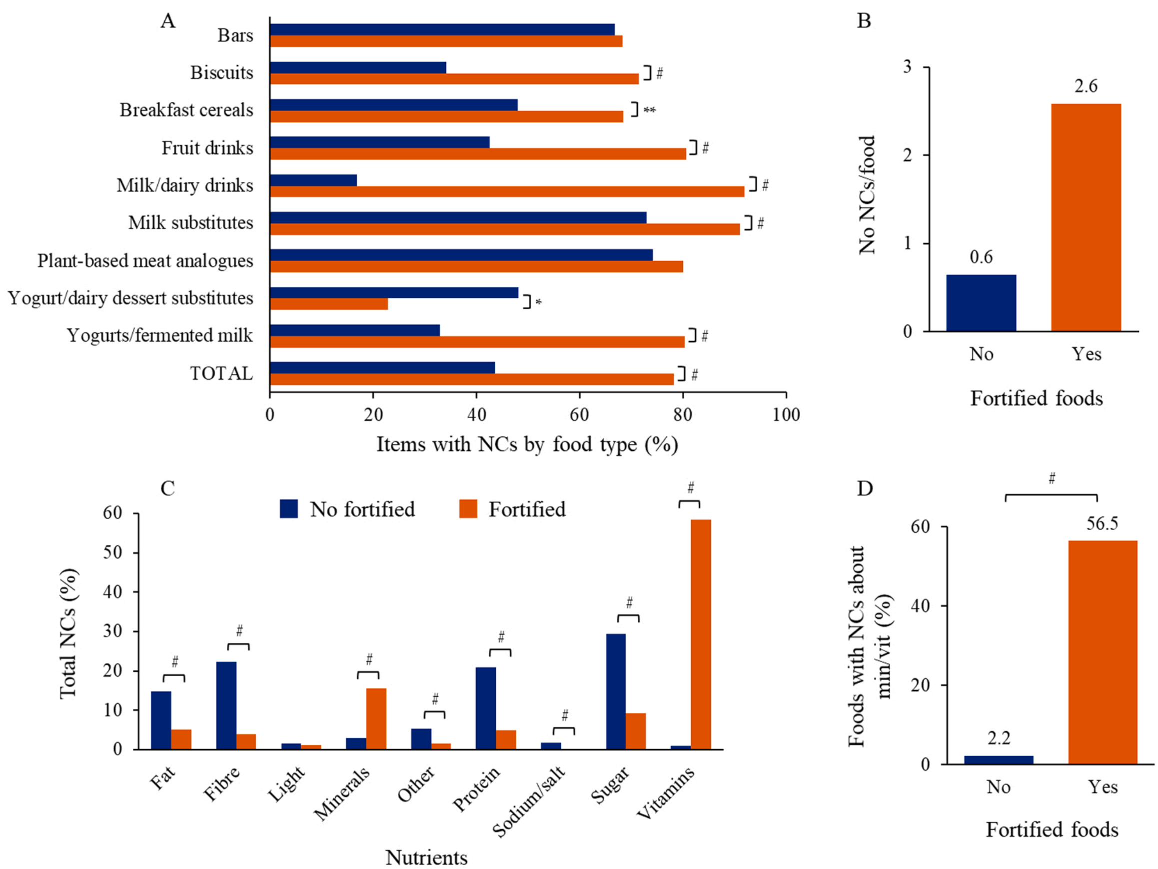

Fig. 2. (A) Presence of Nutrition Claims (NCs) in fortified and unfortified items by food type. (B) Number of NCs per food. (C) Proportion of NCs by nutrient claimed. (D) Percentage of foods with NCs about minerals or vitamins. Min/vit: minerals or vitamins. Only food types with at least 30 items per category were included in these analyses. Statistically significant differences according to: * $p < 0{,}05$; ** $p < 0{,}01$; # $p < 0{,}001$.

composition was compared with that of unfortified products. However, as in the present manuscript, grain or grain products were the main food group fortified with this vitamin. In addition, the use of nutrition claims about vitamins were also very frequent among these foods (Samaniego-Vaesken et al. 2016; Samaniego-Vaesken et al. 2017a).

Our data show that folic acid (B9) is one of the micronutrients with higher fortification rate, yet only 5 %, mainly in milk/dairy drinks, breakfast cereals and bars. A study in Ireland showed twice as much folic acid fortification rate in breakfast cereals (38 % compared to 15.3 %) (Egan et al., 2019). On the contrary, the proportion was lower in milk (11 % compared to 17.3 %), while similar in yogurts (2 % compared to 1 %) (Egan et al., 2019).

Our results may be compared to those obtained in a previous study in Portugal carried out in foods consumed by participants in the IAN-AF 2015–16 study (Martins et al., 2022). Their fortification rates were lower in milk (8.3 % vs 30.6 %), nectars and soft drinks to ours (20.8–26.9 % vs 42.9 %), while similar in yogurts (6.2 % vs. 9.5 %) and biscuits (11.7 % vs 9.8 %) (Martins et al., 2022). However, their rates were higher for breakfast cereals and cereal bars (66.6 % vs 17.9–22.4 %), plant-based drinks and yogurt/dairy dessert substitutes (80.2 % vs 24.8–36.3 %) (Martins et al., 2022).

Vitamin D was the most frequently added micronutrient in the present study (8.3 % of all products), with milk and milk substitutes having the highest rates (28.4 % and 23.2 % respectively). Vitamin D fortification of milk was much higher than in Slovenia (28.4 % vs 4.5 %), while it was similar in milk substitutes (23.2 % vs 22.7 %) (Krusic et al., 2022). On the contrary, we obtained lower fortification rate in yogurt/dairy dessert substitutes (9.2 % vs 19.1 % in the Slovenian work), while similar in breakfast cereals (8.3 % vs 5–6 %) (Krusic et al. 2022). According to our data, vitamins B and iron are the most frequently added micronutrients in cereal products (biscuits, breakfast cereals, bars). This is in agreement with a work in Japan published in 2023, although our rates were much lower (the maximum fortification rate in the present work was 16.5 %, while 37.8–99.7 % in the Japanese study) (Nishijima et al., 2023).

4.2. Food fortification and micronutrient intakes

As mentioned earlier, Vitamin D was the micronutrient most frequently added in the present study. Vitamin D deficiency is widespread in high-income countries, affecting 24 % of the population in the USA, 37 % in Canada and 30–60 % in Europe (Lips et al., 2019; Amrein et al., 2020). In Spain, as many as 93 % of the population 9–75 years present intakes below the 80 % of the EFSA recommendations, according to the ANIBES study (Olza et al., 2017a). Food fortification with vitamin D may result in higher intakes, as well as positive health outcomes (de Jong et al., 2022a; Fonseca et al., 2022; McCourt & O'Sullivan, 2022; Nyakundi et al., 2023). Moreover, "current vitamin D fortification is estimated to prevent approximately 11,000 cancer deaths in the European Union and 27,000 in all European countries considered per year" (Niedermaier et al., 2022). However, our results suggest that the scarce 8.3 % fortification rate obtained in Spain can hardly result in all these positive outcomes. A greater fortification rate in foods as highly consumed as milk and cereal products would help decrease the severe vitamin D deficiency in Spain.

The prevalence of micronutrient deficiency in Spain is also important for other vitamins and minerals. As many as >50 % of the population aged 9–75 years reported intakes below 80 % of the European Food Safety Authority (EFSA) daily recommendations of calcium, magnesium, zinc, vitamins B9, A, E and C, as well as iron in women (Olza et al.,

Table 2
Energy and nutrient density of specific food types. Values in 100 g or 100 ml.

Food types	Fortified	Energy (kcal)			Protein (g)			Carbohydrates (g)			Sugar (g)		
		n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value
Bars	No	208	428 (374; 484)	0.079	208	11.9 (6.9; 27)	0.309	208	46.4 (28.8; 61.9)	< 0.05*	208	23.2 (12.5; 32.1)	0.263
	Yes	60	407 (373; 441)		60	9.7 (6.3; 23)		60	56.3 (41.6; 63.1)		58	25.5 (17.2; 35)	
Biscuits	No	578	475 (452; 497)	< 0.001*	578	6.5 (5.6; 7.5)	0.182	578	64 (61; 69)	< 0.001*	575	23 (18.9; 32)	0.236
	Yes	63	461 (450; 469)		63	6.8 (6; 7.5)		63	68 (65.9; 73)		62	22 (20; 24)	
Breakfast cereals	No	348	380 (366; 422)	0.574	348	10 (8.4; 12)	< 0.001*	348	64 (59; 72)	< 0.001*	344	12.2 (1.3; 20)	< 0.001*
	Yes	76	384 (375; 394)		76	8.5 (7.2; 10)		76	74.9 (67.8; 79.8)		76	21.5 (15.8; 26)	
Fruit drinks	No	144	29 (20; 45)	0.072	143	0.1 (0; 0.3)	< 0.01*	144	6.8 (4.6; 10.1)	0.107	142	6 (4.2; 10)	0.126
	Yes	108	26 (20; 36)		108	0.2 (0.1; 0.3)		107	5.6 (4.8; 8.1)		106	5.2 (4.4; 7.8)	
Milk/dairy drinks	No	281	46 (45; 63)	0.886	281	3.1 (3; 3.2)	< 0.001*	281	4.8 (4.6; 5)	< 0.01*	278	4.8 (4.6; 4.9)	< 0.01*
	Yes	124	50 (44; 60)		124	3.2 (3; 3.9)		124	4.8 (4.7; 5.3)		124	4.8 (4.7; 5.3)	
Milk substitutes	No	213	50 (39; 60)	< 0.01*	214	0.8 (0.5; 1.2)	< 0.05*	213	8.1 (3.6; 10.5)	< 0.001*	214	5 (2; 6)	< 0.01*
	Yes	122	45 (34; 54)		122	1 (0.5; 3)		122	5.2 (2.5; 8.3)		122	3.4 (1.3; 5.2)	
Plant-based meat analogues	No	249	212 (183; 242)	< 0.05*	252	13 (7.1; 18)	0.345	249	13 (6.9; 19)	< 0.01*	252	1.8 (1; 2.8)	< 0.001*
	Yes	30	180 (145; 223)		30	14.7 (11.1; 18)		30	5.9 (4; 12.8)		30	0.8 (0; 1.2)	
Yogurt/dairy dessert substitutes	No	106	90 (78; 111)	< 0.001*	106	1.9 (0.9; 3.7)	< 0.001*	106	11 (5.3; 14.9)	0.108	106	8.3 (2.3; 11.1)	0.802
	Yes	35	76 (59; 85)		35	3.7 (3.6; 3.9)		35	10.5 (5.7; 11.8)		35	8.7 (2.8; 11)	
Yogurts/fermented milk	No	730	75 (54; 96)	< 0.001*	730	3.5 (3; 4.2)	< 0.05*	730	10.7 (5.2; 12.1)	0.264	726	10 (4.9; 12)	0.286
	Yes	77	62 (49; 74)		77	2.9 (2.8; 4.2)		77	10 (5.2; 11)		77	9.4 (5.2; 11)	

Food types	Fortified	Total fat (g)			Saturated fat (g)			Fibre (g)			Sodium (mg)		
		n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value
Bars	No	208	15.7 (11.6; 25)	< 0.01*	206	5.4 (2.9; 9)	0.762	185	6.8 (5; 9.9)	0.325	206	92 (28; 160)	< 0.001*
	Yes	60	13 (9.2; 20.3)		58	4.9 (2.9; 9.6)		52	6.2 (3.4; 9.7)		60	200 (75; 244)	
Biscuits	No	578	20.5 (16.6; 24)	< 0.001*	577	7 (2.3; 12.9)	< 0.001*	461	4 (2.6; 6.1)	0.217	578	240 (152; 320)	< 0.05*
	Yes	63	16 (14.9; 18)		63	3 (1.6; 6.7)		58	3.5 (2.5; 5.3)		63	272 (200; 400)	
Breakfast cereals	No	348	6.7 (3.3; 12.5)	< 0.001*	344	1.3 (0.7; 2.8)	< 0.05*	330	7.8 (5.3; 10)	< 0.01*	341	28 (8; 152)	< 0.001*
	Yes	76	3.5 (1.9; 7)		76	1 (0.5; 2.2)		75	5.6 (4.2; 8.7)		76	264 (140; 341)	
Fruit drinks	No	143	0 (0; 0.1)	0.908	142	0 (0; 0)	0.157	37	0.2 (0; 0.5)	0.558	143	4 (0; 4)	< 0.05*

(*continued on next page*)

Table 2 (*continued*)

Food types	Fortified	Total fat (g)			Saturated fat (g)			Fibre (g)			Sodium (mg)		
		n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value
	Yes	108	0 (0; 0.1)		108	0 (0; 0)		53	0.3 (0.1; 0.5)		108	4 (0; 12)	
Milk/dairy drinks	No	281	1.6 (0.5; 2.3)	0.654	278	1 (0.4; 1.5)	0.067	48	ND	ND	277	52 (40; 52)	< 0.001*
	Yes	124	1.6 (0.5; 2.1)		122	0.8 (0.3; 1.1)		12	ND		123	52 (52; 64)	
Milk substitutes	No	214	1.7 (1; 2.2)	0.192	214	0.3 (0.2; 0.4)	0.065	143	0.5 (0.2; 0.7)	< 0.01*	209	36 (24; 40)	< 0.001*
	Yes	122	1.5 (1.1; 1.9)		122	0.2 (0.2; 0.3)		88	0.6 (0.4; 0.9)		122	40 (36; 56)	
Plant-based meat analogues	No	252	11 (6.9; 15)	0.261	252	1.3 (1; 1.9)	0.669	201	ND	ND	251	520 (440; 640)	0.414
	Yes	30	8.8 (6.5; 13.5)		30	1.3 (0.8; 2.2)		19	ND		30	534 (480; 635)	
Yogurt/dairy dessert substitutes	No	106	3.2 (2.2; 5.5)	< 0.001*	105	0.5 (0.3; 2.8)	< 0.05*	40	ND	ND	106	40 (24; 40)	< 0.05*
	Yes	35	2.1 (2; 2.7)		35	0.4 (0.3; 0.6)		20	ND		35	40 (24; 60)	
Yogurts/fermented milk	No	727	2.3 (0.5; 3.8)	< 0.001*	725	1.6 (0.2; 2.5)	< 0.001*	56	ND	ND	730	44 (40; 52)	0.979
	Yes	77	1.4 (0.4; 1.6)		77	0.8 (0.2; 1)		12	ND		77	40 (40; 60)	

* Statistically significant differences according to $p < 0.05$. Only food types with at least 30 items per category were included in this analysis. n: Foods with data. IR: interquartile range. ND: not determined because of < 30 foods/condition.

2017a, 2017b; Partearroyo et al., 2017; Samaniego-Vaesken et al., 2017b). Following the same criteria, insufficient intake of vitamins B1, B2, B3, B6 were also reported in >20 % of the population (Mielgo-Ayuso et al., 2018). The fortification rates of these micronutrients range from 7.1 % to 0.6 % in the present study, which can hardly significantly improve the micronutrient status of the Spanish population. Many fortified foods belong to highly consumed food types, such as dairy and cereal products, and increasing the rate would benefit the population. However, an important effort is required to add micronutrients which are not commonly use for this purpose.

Some of the foods analysed in this work are widely consumed in Spain and, therefore, have the potential to contribute greatly to reducing micronutrient deficiencies. As many as 87.2 % of the population consume bread (an average of 4.64 kg/year) according to a report released by the Spanish Ministerio de Agricultura, Pesca y Alimentación on food intake in 2023 (MAPA, 2024). This makes bread an excellent target for fortification, although currently only 6.3 % of them are fortified (MAPA, 2024).

Milk also has a high potential for fortification as 62.9 liters/year per person were consumed in Spain in 2023. Our data show that nearly one in three is fortified at present. Vitamin A, D and folic acid are the most frequently added micronutrients and they are among those most deficient in Spain (Olza et al. (2017a), Partearroyo et al. (2017; 2017). However, the acceptance of fortified milk must be increased because only 8.73 liters were consumed in 2023, which barely represents 14 % of total milk intake (MAPA, 2024). Fortified milk is more expensive and this may be one of the mains reasons. Therefore, making it more affordable for the population can help improve the micronutrient status of the population.

Another potential target for fortification are breakfast cereals. Its effectiveness has been demonstrated by the NHANES 2007–2010 data from USA, which showed that unfortified ready-to-eat cereals increased the percentage of people that were below Estimated Average Requirement for niacin, iron, thiamine, B6 vitamin A and zinc (Fulgoni & Buckley, 2015). The average intake of breakfast cereals in Spain is 1.56 kg/person (MAPA, 2024). According to our data, 17.9 % of them are fortified, mainly with vitamin B and iron. Unfortunately, the healthy breakfast cereals (those with no additional ingredients) are not fortified. The results in USA suggest that the fortification of healthy breakfast cereals may improve the deficiencies in vitamin B and iron in Spain (Mielgo-Ayuso et al. (2018), Samaniego-Vaesken et al. (2017b), Samaniego-Vaesken et al. (2017b).

Biscuits may be candidates for fortification, as the intake was as high as 4.84 kg/person in 2023 (MAPA, 2024). However, their nutritional quality should be taken into account before promoting them to improve the micronutrient status of the population (see Section 4.3 below).

Consumption of fortified foods can be of concern because of the potential risk of exceeding the tolerable upper intake levels set for some micronutrients by EFSA (EFSA, 2024). However, this does not seem to be the case for the general population when the fortification policy is voluntary as it is in Spain (Tarasuk & Brassard, 2021).

4.3. *The case of plant-based foods*

Our results show that plant-based foods are among the most frequently fortified foods: one in three milk substitutes, one in four yogurt/dairy dessert substitutes and one in ten meat analogues. The global plant-based food market is on the rise and is predicted to growth three fold from 2023 to 2033 (Good Food Institute, n.d.; Future Market Insights, 2024b). These foods are usually presented by the industry as healthier alternatives to animal-based foods. However, their main drawback is the absence of some micronutrients naturally present in animal-based foods. In fact, substitution of milk with unfortified vegetable drinks may be a risk for deficiencies in calcium, zinc, iodine, vitamins B2, B12, D and A (Scholz et al., 2020). According to our data,

Table 3
Classification of foods as high in critical nutrients according to the PAHO—NPM, by food type (PAHO, 2016).

Food Types	Fortified	Less Healthy			High Fat			High Free Sugar			High Saturated Fat			High Sodium			Sweeteners (LNCS)		
		n	No (%)	*p*-value	n	No (%)	*p*-value	n	No (%)	*p*-value	n	No (%)	*p*-value	n	No (%)	*p*-value	n	No (%)	*p*-value
Bars	No	185	180 (97.3)	1	205	132 (64.4)	< 0.001*	186	129 (69.4)	0.193	205	122 (59.5)	1	203	2 (1)	1	205	36 (17.6)	0.226
	Yes	58	57 (98.3)		60	23 (38.3)		58	46 (79.3)		58	34 (58.6)		60	1 (1.7)		60	6 (10)	
Biscuits	No	576	573 (99.5)	0.859	578	484 (83.7)	< 0.001*	577	490 (84.9)	0.090	577	336 (58.2)	< 0.001*	578	53 (9.2)	0.496	578	58 (10)	< 0.05*
	Yes	63	62 (98.4)		63	40 (63.5)		63	59 (93.7)		63	22 (34.9)		63	8 (12.7)		63	1 (1.6)	
Breakfast cereals	No	341	184 (54)	< 0.001*	348	67 (19.3)	< 0.01*	347	146 (42.1)	< 0.001*	347	34 (9.8)	< 0.05*	342	27 (7.9)	< 0.05*	348	8 (2.3)	0.385
	Yes	75	66 (88)		76	3 (3.9)		75	61 (81.3)		76	1 (1.3)		76	12 (15.8)		76	0 (0)	
Fruit drinks	No	140	140 (100)	1	143	3 (2.1)	1	142	140 (98.6)	0.602	142	4 (2.8)	0.939	143	11 (7.7)	0.831	144	77 (53.5)	< 0.05*
	Yes	108	108 (100)		108	2 (1.9)		108	108 (100)		108	2 (1.9)		108	10 (9.3)		108	73 (67.6)	
Milk/dairy drinks	No	281	68 (24.2)	0.962	281	1 (0.4)	< 0.05*	281	53 (18.9)	0.125	281	42 (14.9)	0.293	281	25 (8.9)	0.292	281	12 (4.3)	< 0.05*
	Yes	124	31 (25)		124	5 (4)		124	15 (12.1)		124	13 (10.5)		124	16 (12.9)		124	14 (11.3)	
Milk substitutes	No	208	199 (95.7)	0.144	213	91 (42.7)	< 0.01*	213	164 (77)	1	213	33 (15.5)	< 0.05*	208	45 (21.6)	< 0.001*	214	3 (1.4)	0.117
	Yes	122	121 (99.2)		122	71 (58.2)		122	94 (77)		122	9 (7.4)		122	54 (44.3)		122	6 (4.9)	
Plant-based meat	No	246	239 (97.2)	0.748	249	196 (78.7)	0.435	247	2 (0.8)	1	249	32 (12.9)	0.199	248	238 (96)	0.548	252	0 (0)	1
	Yes	30	30 (100)		30	26 (86.7)		30	0 (0)		30	7 (23.3)		30	30 (100)		30	0 (0)	
Yogurt/dairy dessert substitutes	No	106	99 (93.4)	0.288	106	59 (55.7)	< 0.01*	106	80 (75.5)	0.301	106	36 (34)	0.094	106	1 (0.9)	< 0.001*	106	0 (0)	1
	Yes	35	30 (85.7)		35	8 (22.9)		35	30 (85.7)		35	6 (17.1)		35	9 (25.7)		35	0 (0)	
Yogurts/fermented milk	No	726	586 (80.7)	< 0.01*	728	237 (32.6)	< 0.001*	730	441 (60.4)	0.515	726	408 (56.2)	0.212	730	131 (17.9)	0.311	730	141 (19.3)	< 0.001*
	Yes	77	74 (96.1)		77	8 (10.4)		77	50 (64.9)		77	37 (48.1)		77	18 (23.4)		77	35 (45.5)	
TOTAL	No	2809	2268 (80.7)	0.086	2851	1270 (44.5)	< 0.001*	2829	1645 (58.1)	< 0.001*	2846	1047 (36.8)	< 0.001*	2839	533 (18.8)	< 0.05*	2858	335 (11.7)	< 0.001*
	Yes	692	579 (83.7)		695	186 (26.8)		692	463 (66.9)		693	131 (18.9)		695	158 (22.7)		695	135 (19.4)	

* Statistically significant differences according to $p < 0.05$. Only food types with at least 30 items per category were included in this analysis. %: Percentage within the food type. n: Foods with data. No: foods exceeding the threshold or with LNCS. LNCS: low- or no-calorie sweeteners. Thresholds used to consider foods as high in critical nutrients are (PAHO, 2016): ≥30 % of total energy from total fat, ≥10 % of total energy from free sugars, ≥10 % of total energy from saturated fat, ≥1 mg sodium/kcal.

calcium and vitamin D are the main micronutrients used to fortify vegetable drinks, yet only in 36 % and 23.2 % of them, respectively. These rates were even lower for yogurt/dairy dessert substitutes (24.8 % and 9.2 % for calcium and vitamina D respectively). Other micronutrients were only added in 1.2 % - 11.3 % of products. These rates were lower than those obtained in a study in Australia with 115 plant-based milk alternatives (57 %) (Zhang et al., 2020). Surprisingly, higher rates (76 %) were observed in a study with non-organic plant-based dairy alternatives and yogurt/desserts across Europe (including Spain), with calcium as the leading micronutrient (Medici et al., 2023). Therefore, our results show that plant-based dairy substitutes are largely unfortified and, when they are used as dairy substitutes, micronutrient deficiencies already present in the population may worsen.

Meat is a particularly important source of high bioavailable iron, vitamin B12 and zinc. Our results show that less than one in ten plant-based analogues were fortified with iron or vitamin B12, with no addition at all of zinc. Higher rates were obtained in Australia (12.1–15.2 %) (Melville et al., 2023). Replacing meat with these analogues may aggravate the already high deficiency rates in iron and zinc in the Spanish population (Olza et al., 2017b; Samaniego-Vaesken, Partearroyo et al., 2017b).

4.4. Food fortification and health

Regardless of the consequences of consuming fortified foods in the micronutrient intake of the population, the main conclusion of this work is that most of these foods are not healthy. The evaluation of the nutritional quality was carried out by applying the Pan American Health Organization and the World Health Organization – Regional Office in Iberoamerica, (PAHO, 2016). The criteria include the content of free sugar, sodium, total and saturated fat and the presence of sweeteners (PAHO, 2016). These nutrients and sweeteners are negatively associated to health.

Two of three fortified foods were high in free sugar (66.9 %), higher rate than for the unfortified (58.1 %). According to the 2015 report by WHO, "a high level of free sugars intake is of concern because of its association with poor dietary quality, obesity and risk of non-communicable diseases" (WHO, 2015). In addition, "intake of free sugars increases overall energy intake and may reduce the intake of foods containing more nutritionally adequate calories" (WHO, 2015).

One in four fortified foods were high in total fat (26.8 %), while more than half of biscuits, milk substitutes and plant-based meat exceeded the threshold (63.5 %, 58.2 % and 86.7 % respectively). In the opinion of WHO in 2023, "evidence from a systematic review of randomized controlled trials conducted in non-dieting adults found that reducing intake of total fat led to lower body weight, body mass index, waist circumference and percentage of body fat" (WHO, 2023b). Saturated fat is particularly negative to health and one in five fortified foods in the current study presented high values (18.9 %). The recent WHO guideline on saturated fatty acid intake concludes that "lowering saturated fatty acid intake reduces low-density lipoprotein (LDL) cholesterol (high certainty evidence) and CVD risk (moderate certainty evidence), and may be associated with reduced risk of all-cause mortality (i.e. death from any cause) and coronary heart disease (both very low certainty evidence)" (WHO, 2023a).

Nearly one in four fortified foods in the present work exceeded the threshold to be considered high in sodium (22.7 %). Almost 2 million deaths each year are associated with excessive intake of sodium, which is the largest number of diet-related deaths (WHO, 2023d). Its negative effects on the cardiovascular system is the main mechanism (WHO, 2023d). Most dietary sodium comes from processed foods and the global sodium intake, including that in Spain, is double the recommended (Ortega et al., 2011; WHO, 2023d).

An important proportion of fortified foods in the present work contained low- or no-calorie sweeteners (19.4 %), particularly fruit drinks and yogurts/fermented milk (67.6 % and 45.5 % respectively). After decades of much controversy, WHO suggested in 2023 "that non-sugar sweeteners not be used as a means of achieving weight control or reducing the risk of noncommunicable diseases" (WHO, 2023c). In addition, evidence from long-term prospective observational studies concluded that "higher intakes of non-sugar sweeteners were associated with increased risk of type 2 diabetes, cardiovascular diseases and cardiovascular mortality, and all-cause mortality" (WHO, 2023c). Polyols were not included in this report, though they were already not recommended by the Pan American Health Organization and the World Health Organization – Regional Office in Iberoamerica in 2016 (PAHO, 2016).

Last, but not least, most of these foods are ultraprocessed (UPF) according to the NOVA classification (FAO, 2018). According to studies, UPF are associated with higher chronic diseases risk and greater all-cause mortality (Forde & Decker, 2022; Lawrence, 2021). They have been related also with greater risk of overweight, obesity and cancer (Forde & Decker, 2022; Kliemann., 2023). Whether the negative impact on health is due to the processing or the nutrient composition is a matter of debate (Forde & Decker, 2022). Therefore, the addition of micronutrients to UPF and the use of NCs may increase their intake and negatively affect health (Kroker-Lobos et al., 2022).

4.5. Strengths and limitations

This work presents important strengthçs:

- This is the first comprehensive research on the micronutrient fortification of foods in Spain.
- This is also the first report on the nutrient composition and nutritional quality of micronutrient fortified foods and comparing them with unfortified equivalents.
- This analysis includes large samples of twelve different food types

It also has some limitations, which are to be mentioned:

- Selection of brands did not follow criteria based on customers' purchases or the most popular products;
- Data collected were reliant on the accuracy of the information provided on the manufacturers' and supermarkets' websites;
- Some mineral fortification may have been wrongly attributed when one ingredient provides two minerals because it is impossible to determine the manufacturer's true intention.

5. Conclusion

This work indicates that voluntary micronutrient fortification in Spain is scarce and can hardly address the deficiencies reported in the population. In this regard, mandatory fortification may be more efficient. However, it should not be used to promote unhealthy foods or to compensate for the presence of nutrients negatively associated to health. Increasing micronutrient intake through fortified foods cannot lead to further deterioration of the diet. In view of these results, we can conclude that voluntary fortification in Spain is market-driven rather than a means to improve the health of the population. Governments should seriously consider this issue and only healthy foods should be allowed to be fortified to protect public health.

Funding statement

This research received no external funding. The publication fee was satisfied by internal funding.

Ethical statement

No humans or animals were used in the present study.

CRediT authorship contribution statement

Marta Rodríguez: Validation, Resources, Investigation. **Marta Beltrá:** Writing – review & editing, Validation, Resources, Data curation. **Fernando Borrás:** Methodology, Formal analysis. **Ana B. Ropero:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank all students who contributed to the BADALI Project so generously over the years.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2025.100947.

Data availability

Some of the data is available online at https://badali.umh.es. The entire food database will be made available on request.

References

Amrein, K., Scherkl, M., Hoffmann, M., Neuwersch-Sommeregger, S., Köstenberger, M., Tmava Berisha, A., Martucci, G., Pilz, S., & Malle, O. (2020). Vitamin D deficiency 2.0: An update on the current status worldwide. *European Journal of Clinical Nutrition, 74*(11), 1498–1513. .ncbi.nlm.nih.gov/31959942/.

Ballco, P., & Gracia, A. (2022). Tackling nutritional and health claims to disentangle their effects on consumer food choices and behaviour: A systematic review. *Food Quality and Preference, 101*, Article 104634. https://doi.org/10.1016/j.foodqual.2022.104634

Beltrá, M., Soares-Micoanski, K., Navarrete-Muñoz, E. M., & Ropero, A. B. (2020). Nutrient composition of foods marketed to children or adolescents sold in the Spanish market: Are they any better? *International Journal of Environmental Research and Public Health, 17*, 7699. https://doi.org/10.3390/ijerph17207699

Bimbo, F., Bonanno, A., Nocella, G., Viscecchia, R., Nardone, G., De Devitiis, B., & Carlucci, D. (2017). Consumers' acceptance and preferences for nutrition-modified and functional dairy products: A systematic review. *Appetite, 113*, 141–154. https://doi.org/10.1016/j.appet.2017.02.031

Bird, J. K., Barron, R., Pigat, S., & Bruins, M. J. (2022). Contribution of base diet, voluntary fortified foods and supplements to micronutrient intakes in the UK. *Journal of Nutritional Science, 11*, e51. https://doi.org/10.1017/jns.2022.47

Castellini, G., Vezzulli, F., Lambri, M., Sacchettini, G., Graffigna, G., Marques, A., & Capri, E. (2022). Perceptions and liking distortion from information about the nutritional upgrades in biofortified seafood products. *Foods (Basel, Switzerland), 11*, 2808. https://doi.org/10.3390/foods11182808

Base de Datos de Alimentos (BADALI). n.d. Retrieved from https://badali.umh.es. Accessed May 5, 2025.

Base de Datos Española de Composición de Alimentos (BEDCA). Retrieved from http://www.bedca.net. Accessed May 27, 2024. 2006.

Centers for Disease Control and Prevention (CDC) (2023). Micronutrients. Retrieved from https://www.cdc.gov/nutrition/php/micronutrients/index.html. Accessed May 27, 2024.

Chiba, T., Tanemura, N., & Nishijima, C. (2021). The perception of vitamins and their prevalence in fortified food and supplements in Japan. *Nutrients, 13*, 3136. https://doi.org/10.3390/nu13093136

Chiba, T., Tanemura, N., & Nishijima, C. (2022). The perception of minerals and their prevalence in fortified foods and supplements in Japan. *Nutrients, 14*, 2586. https://doi.org/10.3390/nu14132586

Clark, B., Hill, T., & Hubbard, C. (2019). Consumers perception of vitamin D and fortified foods. *British Food Journal, 121*(9), 2205–2218. https://doi.org/10.1108/BFJ-04-2018-0249

Das, J. K., Salam, R. A., Mahmoo, S. B., Moin, A., Kumar, R., Mukhtar, K., Lassi, Z. S., & Bhutta, Z. A. (2019). Food fortification with multiple micronutrients: Impact on health outcomes in general population. *Cochrane Database of Systematic Reviews, 12*. https://doi.org/10.1002/14651858.CD011400.pub2

de Jong, M. H., Nawijn, E. L., & Verkaik-Kloosterman, J. (2022a). Contribution of fortified margarines and other plant-based fats to micronutrient intake in The Netherlands. *European Journal of Nutrition, 61*(2022), 1893–1904. https://doi.org/10.1007/s00394-021-02757-z
de Jong, M. H., Nawijn, E. L., & Verkaik-Kloosterman, J. (2022b). Contribution of voluntary fortified foods to micronutrient intake in The Netherlands. *European Journal of Nutrition, 61*, 1649–1663. https://doi.org/10.1007/s00394-021-02728-4
Egan, E., Kelly, F., & Sweeney, M. R. (2019). Voluntary folic acid fortification levels of food staples in Ireland continue to decline: Further implications for passive folic acid intakes? *Journal of Public Health, 43*(2), 281–286. https://doi.org/10.1093/pubmed/fdz125
European Food Safety Authority (EFSA). (2024). Overview on tolerable upper Intake levels as derived by the Scientific Committee on Food (SCF) and the EFSA Panel on Dietetic Products. *Nutrition and Allergies (NDA)*. Retrieved from https://www.efsa.europa.eu/sites/default/files/2024-05/ul-summary-report.pdf Accessed June 20, 2024.
European Parliament. (2006). Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods. Retrieved from https://eur-lex.europa.eu/eli/reg/2006/1924/2014-12-13. Accessed June 20, 2024.
Food and Agriculture Organization of the United Nations (FAO). (2018). Ultra-processed foods, diet quality, and health using the NOVA classification system. Retrieved from https://www.fao.org/fsnforum/resources/trainings-tools-and-databases/ultra-processed-foods-diet-quality-and-health-using-nova Accessed July 30, 2024.
Fonseca, R. K., Batista, C., Rocha, A., Brandão-Lima, P. N., Barbosa, G., Araújo, L., & Viana, L. (2022). Role of food fortification with vitamin D and calcium in the bone remodeling process in postmenopausal women: A systematic review of randomized controlled trials. *Nutrition Reviews, 80*(4), 826–837. https://doi.org/10.1093/nutrit/nuab055
Forde, C. G., & Decker, E. A. (2022). The importance of food processing and eating behavior in promoting healthy and sustainable diets. *Annual Review of Nutrition, 42*, 377–399. https://doi.org/10.1146/annurev-nutr-062220-030123
Fulgoni, V. L., & Buckley, R. B. (2015). The contribution of fortified ready-to-eat cereal to vitamin and mineral intake in the U.S. Population, NHANES 2007-2010. *Nutrients, 25, 7*(6), 3949–3958. https://doi.org/10.3390/nu7063949
Future Market Insights. (2024a). Fortified Foods Market. Retrieved from https://www.futuremarketinsights.com/reports/fortified-food-market. Accessed May 27, 2024.
Future Market Insights. (2024b). Plant-based food market outlook (2023 to 2033). Retrieved from https://www.futuremarketinsights.com/reports/plant-based-food-market. Accessed June 21, 2024.
Chinnici, G., Zarba, C., Privitera, D. S., Matarazzo, A., & Scuderi, A. (2023). Food attributes of fortified foods: An analysis of consumption behaviour. *Proceedings of 23rd International Multidisciplinary Scientific GeoConference SGEM 2023, 23*, 223–230. https://doi.org/10.5593/sgem2023V/6.2/s25.28
Glanbia Nutritionals. (2022). Opportunities in fortifying functional food and beverage in Europe. Retrieved from https://www.glanbianutritionals.com/en/nutri-knowledge-center/insights/opportunities-fortifying-functional-food-and-beverage-europe. Accessed May 27, 2024.
Good Food Institute. The plant-based food industry is evolving. Retrieved from https://gfi.org/marketresearch/. Accessed June 21, 2024.
Gulyas, B. Z., Mogeni, B., Jackson, P., Walton, J., & Caton, S. J. (2024). Biofortification as a food-based strategy to improve nutrition in high-income countries: A scoping review. *Critical Reviews in Food Science and Nutrition*, 1–22. https://doi.org/10.1080/10408398.2024.2402998
Han, X., Ding, S., Lu, J., & Li, Y. (2022). Global, regional, and national burdens of common micronutrient deficiencies from 1990 to 2019: A secondary trend analysis based on the Global Burden of Disease 2019 study. *EClinicalMedicine, 44*, Article 101299. https://doi.org/10.1016/j.eclinm.2022.101299
Hombali, A. S., Solon, J. A., Venkatesh, B. T., Nair, N. S., & Peña-Rosas, J. P. (2019). Fortification of staple foods with vitamin A for vitamin A deficiency. *Cochrane Database of Systematic Reviews, 5*. https://doi.org/10.1002/14651858.CD010068.pub2
Iles, I. A., Nan, X., & Verrill, L. (2017). Nutrient content claims: How they impact perceived healthfulness of fortified snack foods and the moderating effects of nutrition facts labels. *Health Communication, 33*(10), 1308–1316. https://doi.org/10.1080/10410236.2017.1351277
Kliemann, N., Rauber, F., Bertazzi Levy, R., Viallon, V., Vamos, E. P., Cordova, R., Freisling, H., Casagrande, C., Nicolas, G., Aune, D., Tsilidis, K. K., Heath, A., Schulze, M. B., Jannasch, F., Srour, B., Kaaks, R., Rodriguez-Barranco, M., Tagliabue, G., Agudo, A., Panico, S., …, & Huybrechts, I. (2023). Food processing and cancer risk in Europe: Results from the prospective EPIC cohort study. *The Lancet. Planetary health, 7*(3), e219–e232. https://doi.org/10.1016/S2542-5196(23)00021-9
Kroker-Lobos, M. F., Mazariegos, M., Guamuch, M., & Ramirez-Zea, M. (2022). Ultraprocessed products as food fortification alternatives: A critical appraisal from Latin America. *Nutrients, 14*(7), 1413. https://doi.org/10.3390/nu14071413
Krusic, S., Hribar, M., Hafner, E., Žmitek, K., & Pravst, I. (2022). Use of branded food composition database for the explotation of food fortification practices: A case study on vitamin D in the Slovenian food supply. *Frontiers in Nutrition, 8*, 775163. https://doi.org/10.3389/fnut.2021.775163
Lawrence, M. (2021). Ultraprocessed foods and cardiovascular health: It's not just about the nutrients. *The American journal of clinical nutrition, 113*(2), 257–258. https://doi.org/10.1093/ajcn/nqaa333
Lips, P., Cashman, K. D., Lamberg-Allardt, C., Bischoff-Ferrari, H. A., Obermayer-Pietsch, B., Bianchi, M. L., Stepan, J., Fuleihan, G. E. H., & Bouillon, R. (2019). on behalf of the Working Group on Vitamin D of the European Calcified Tissue Society. Current vitamin D status in European and Middle East countries and strategies to prevent vitamin D deficiency: A position statement of the European Calcified Tissue Society. *European Journal of Endocrinology, 180*(4), P23–P54. https://doi.org/10.1530/EJE-18-0736
Martins, A. P., Correia, D., Carvalho, C., Lopes, C., Gomes, A. M., & Torres, D. (2022). Análise da oferta de alimentos fortificados em micronutrientes em Portugal. *Acta Portuguesa de Nutrição, 29*, 10–19. https://doi.org/10.21011/apn.2022.03
Masson, E., Debucquet, G., Fischler, C., & Merdji, M. (2016). French consumers' perceptions of nutrition and health claims: A psychosocial-anthropological approach. *Appetite, 105*, 618–629. https://doi.org/10.1016/j.appet.2016.06.026
McCourt, A. F., & O'Sullivan, A. M. (2022). Using food fortification to improve vitamin D bioaccessibility and intakes. *The Proceedings of the Nutrition Society, 81*(1), 99–107. https://doi.org/10.1017/S0029665121003803
Medici, E., Craig, W. J., & Rowland, I. A. (2023). Comprehensive analysis of the nutritional composition of plant-based drinks and yogurt alternatives in Europe. *Nutrients, 15*, 3415. https://doi.org/10.3390/nu15153415
Melville, H., Shahid, M., Gaines, A., McKenzie, B. L., Alessandrini, R., Trieu, K., Wu, J. H. Y., Rosewarne, E., & Coyle, D. H. (2023). The nutritional profile of plant-based meat analogues available for sale in Australia. *Nutrition & Dietetics, 80*(2), 211–222. https://doi.org/10.1111/1747-0080.12793
Mielgo-Ayuso, J., Aparicio-Ugarriza, R., Olza, J., Aranceta-Bartrina, J., Gil, Á., Ortega, R. M., Serra-Majem, L., Varela-Moreiras, G., & González-Gross, M. (2018). Dietary intake and food sources of niacin, riboflavin, thiamin and vitamin B6 in a representative sample of the Spanish population. The ANIBES Study. *Nutrients, 10*, 846. https://doi.org/10.3390/nu10070846
Ministerio de Agricultura, Pesca y Alimentación (MAPA). (2024). Informe Anual de Consumo de Alimentos 2023. Retrieved from https://www.mapa.gob.es/eu/alimentacion/temas/consumo-tendencias/informe_2023_baja_tcm35-685878.pdf. Accessed June 26, 2024.
Ministerio de Salud. Subsecretaría de Salud Pública. Chile. (2015). Diario Oficial de la República de Chile. Cuerpo I—12. No 41.193. *(IdDO 918813) Modifica Decreto Supremo No 977, de 1996, Reglamento Sanitario de los Alimentos Núm, 13*, 2015. Retrieved from https://www.minsal.cl/wp-content/uploads/2015/08/decreto_etiquetado_alimentos_2015.pdf Accessed May 27, 2024.
Newman, J. C., Malek, A. M., Hunt, K. J., & Marriott, B. P. (2019). Nutrients in the US diet: Naturally occurring or enriched/fortified food and beverage sources, plus dietary supplements: NHANES 2009–2012. *The Journal of Nutrition, 149*(8), 1404–1412. https://doi.org/10.1093/jn/nxz066
Niedermaier, T., Gredner, T., Kuznia, S., Schöttker, B., Mons, U., Lakerveld, J., Ahrens, W., Brenner, H., & On behalf of the PEN-Consortium. (2022). Vitamin D food fortification in European countries: The underused potential to prevent cancer deaths. *European Journal of Epidemiology, 37*, 309–320. https://doi.org/10.1007/s10654-022-00867-4
Nishijima, C., Sato, Y., & Chiba, T. (2023). Nutrient intake from voluntary fortified foods and dietary supplements in Japanese consumers: A cross-sectional online survey. *Nutrients, 15*, 3093. https://doi.org/10.3390/nu15143093
Nyakundi, P. N., Némethné Kontár, Z., Kovács, A., Járomi, L., Zand, A., & Lohner, S. (2023). Fortification of staple foods for household use with vitamin D: An overview of systematic reviews. *Nutrients, 15*, 3742. https://doi.org/10.3390/nu15173742
Olza, J., Aranceta-Bartrina, J., González-Gross, M., Ortega, R. M., Serra-Majem, L., Varela-Moreiras, G., & Gil, Á. (2017a). Reported dietary intake, disparity between the Reported consumption and the level needed for adequacy and food sources of calcium, phosphorus, magnesium and vitamin D in the Spanish population: Findings from the ANIBES study †. *Nutrients, 9*, 168. https://doi.org/10.3390/nu9020168
Olza, J., Aranceta-Bartrina, J., González-Gross, M., Ortega, R. M., Serra-Majem, L., Varela-Moreiras, G., & Gil, Á. (2017b). Reported dietary intake and food sources of zinc, selenium, and vitamins A, E and C in the Spanish population: Findings from the ANIBES study. *Nutrients, 9*, 697. https://doi.org/10.3390/nu9070697
Pan American Health Organization (PAHO). Nutrient Profile Model. (2016). Retrieved from https://iris.paho.org/bitstream/handle/10665.2/18621/9789275118733_eng.pdf. Accessed Jun 20, 2024.
Ortega, R. M., López-Sobaler, A. M., Ballesteros, J. M., Pérez-Farinós, N., Rodríguez-Rodríguez, E., Aparicio, A., … Andrés, P. (2011). Estimation of salt intake by 24 h urinary sodium excretion in a representative sample of Spanish adults. *British Journal of Nutrition, 105*, 787–794. https://doi.org/10.1017/S000711451000423X
Partearroyo, T., Samaniego-Vaesken, M. D. L., Ruiz, E., Olza, J., Aranceta-Bartrina, J., Gil, A., González-Gross, M., Ortega, R. M., Serra-Majem, L., & Varela-Moreiras, G. (2017). Dietary sources and intakes of folates and vitamin B_{12} in the Spanish population: Findings from the ANIBES study. *PLoS ONE, 12*(12), Article e0189230. https://doi.org/10.1371/journal.pone.0189230
Peña-Rosas, J. P., Mithra, P., Unnikrishnan, B., Kumar, N., De-Regil, L. M., Nair, N. S., Garcia-Casal, M. N., & Solon, J. A. (2019). Fortification of rice with vitamins and minerals for addressing micronutrient malnutrition. *Cochrane Database of Systematic Reviews*, 10. https://doi.org/10.1002/14651858.CD009902.pub2
Pistorio, E., Chinnici, G., Zarba, C., Bellia, C., & Pappalardo, G. (2023). The revolution of functional food: A market analysis. *Proceedings of 23rd International Multidisciplinary Scientific GeoConference SGEM 2023, 23*, 433–441. https://doi.org/10.5593/sgem2023V/6.2/s25.53
Precedence Research. (2023). Food fortification market. Retrieved from https://www.precedenceresearch.com/food-fortification-market. Accessed May 27, 2024.
Reitano, M., Selvaggi, R., Chinnici, G., Pappalardo, G., Yagi, K., & Pecorino, B. (2024). Athletes preferences and willingness to pay for innovative high-protein functional foods. *Appetite, 203*, Article 107687. https://doi.org/10.1016/j.appet.2024.107687
Rramani, Q., Barakat, Y., Jacob, G., Ohla, K., Lim, S. H.l., Schicker, D., Freiherr, J., Saruco, E., Pleger, B., Weber, B., & Schultz, J. (2023). Nutrition claims influence expectations about food attributes, attenuate activity in reward-associated brain

regions during tasting, but do not impact pleasantness. *Brain and Behavior, 13*, e2828. https://doi.org/10.1002/brb3.2828

Ropero, A. B., Marquina, E., Sarmiento, V. M., & Beltrá, M. (2017). BADALI: Una herramienta de promoción de la salud. *Revista Española de Nutrición Humana y Dietética, 21*, 335–350. https://doi.org/10.14306/renhyd.21.4.377

Ropero, A. B., Borrás, F., Rodríguez, M., & Beltrá, M. (2023). Nutritional description of organic and conventional food products in Spain: The BADALI Project. *Nutrients, 15*, 1876. https://www.mdpi.com/2072-6643/15/8/1876.

Samaniego-Vaesken, M. D. L., Alonso-Aperte, E., & Varela-Moreiras, G. (2016). Voluntary fortification with folic acid in Spain: An updated food composition database. *Food Chemistry, 193*, 148–153. https://doi.org/10.1016/j.foodchem.2014.06.046

Samaniego-Vaesken, M. D. L., Alonso-Aperte, E., & Varela-Moreiras, G. (2017a). Voluntary folic acid fortification levels and nutrient composition of food products from the Spanish market: A 2011-2015 update. *Nutrients, 9*(3), 234. https://doi.org/10.3390/nu9030234

Samaniego-Vaesken, M. D. L., Partearroyo, T., Olza, J., Aranceta-Bartrina, J., Gil, Á., González-Gross, M., Ortega, R. M., Serra-Majem, L., & Varela-Moreiras, G. (2017b). Iron intake and dietary sources in the Spanish population: Findings from the ANIBES study. *Nutrients, 9*, 203. https://doi.org/10.3390/nu9030203

Scholz-Ahrens, K. E., Ahrens, F., & Barth, C. A. (2020). Nutritional and health attributes of milk and milk imitations. *European Journal of Nutrition, 59*, 19–34. https://doi.org/10.1007/s00394-019-01936-3

Senna, S. M., Afonso, I., Urquizar, C. F., Galvão, C., & Rezende, L. (2022). Influence of nutrition claims on different models of front-of package nutritional labelling in supposedly healthy foods: Impact on the understanding of nutritional information, healthfulness perception, and purchase intention of Brazilian consumers. *Front. Nutrition, 9*, Article 921065. https://doi.org/10.3389/fnut.2022.921065

Swan, G. E., Powell, N. A., Knowles, B. L., Bush, M. T., & Levy, L. B. (2018). A definition of free sugars for the UK. *Public Health Nutrition, 21*(9), 1636–1638. https://doi.org/10.1017/S136898001800085X

Tarasuk, V., & Brassard, D. (2021). The effect of consuming voluntarily fortified food and beverages on usual nutrient intakes in the Canadian population. *Food & Nutrition Research, 4*, 65. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8494267/#:~:Text=doi%3A%C2%A010.29219/fnr.v65.5256.

Tian, Y., Zhu, H., Zhang, L., & Chen, H. (2022). Consumer preference for nutritionally fortified eggs and impact of health benefit information. *Foods (Basel, Switzerland), 11*, 1145. https://doi.org/10.3390/foods11081145

Verrill, L., Wood, D., Cates, S., Lando, A., & Zhang, Yuanting (2017). Vitamin-fortified snack food may lead consumers to make poor dietary decisions. *Journal of the Academy of Nutrition and Dietetics, 117*(3), 376–385. https://doi.org/10.1016/j.jand.2016.10.008

World Health Organization (WHO) (2015). Guideline: Sugars intake for adults and children. Retrieved from http://apps.who.int/iris/bitstream/10665/149782/1/9789241549028_eng.pdf?. Accessed May 27, 2024.

World Health Organization (WHO) (n. d.). Micronutrients. Retrieved from https://www.who.int/health-topics/micronutrients#tab=tab_1 Accessed May 27, 2024.

World Health Organization. (WHO) (2023a). Saturated fatty acid and trans-fatty acid intake for adults and children: WHO guideline. Retrieved from https://www.who.int/publications/i/item/9789240073630. Accessed September 10, 2024.

World Health Organization. (WHO) (2023b). Total fat intake for the prevention of unhealthy weight gain in adults and children: WHO guideline summary. Retrieved from https://iris.who.int/handle/10665/375574. Accessed September 10, 2024.

World Health Organization. (WHO) (2023c). Use of non-sugar sweeteners: WHO guideline. Retrieved from https://www.who.int/publications/i/item/9789240073616. Accessed July 30, 2024.

World Health Organization. (WHO) (2023d). WHO global report on sodium intake reduction. Retrieved from https://www.who.int/publications/i/item/9789240069985. Accessed September 10, 2024.

Zhang, Y. Y., Hughes, J., & Grafenauer, S. (2020). Got Mylk? The emerging role of Australian plant-based milk alternatives as A cow's milk substitute. *Nutrients, 12*, 1254. https://doi.org/10.3390/nu12051254

Table S1

Description of the food types included in the study.

Types	Foods
Bars	Bars made of cereals, legumes, dry fruit or nuts with or without added ingredients
Biscuits	All kinds of biscuits according to their commercial name, including wafers. Savoury biscuits were excluded
Bread	Bread (soft) and similar products made with yeast
Breakfast cereals	Flakes, muesli, granola, extruded, ready-to-eat cereals
Cereal cakes/crackers	Cereal cakes and crackers with no yeast or gasifiers added
Fruit drinks	Drinks with a minimum of 5% fruit or juice (juices and smoothies are not included)
Milk/dairy drinks	All kinds of milk, flavoured milk shakes and milk with other ingredients
Milk substitutes	Vegetable drinks made of soya, oat, rice, coco, nuts, tigernut, canary seed or any other vegetable ingredient except tomato
Plant-based meat analogues	Any product made to resemble meat, made with plant-based ingredients
Toasted bread and similar	Toasted bread and similar products made with yeast (low water content)
Yogurt/dairy dessert substitutes	Fermented products and desserts made of plant-based drinks
Yogurts/fermented milk	Yogurts, milk fermented with alternative bacteria (dairy desserts are not included)

Table S2

Items with added minerals or vitamins, by food type and micronutrient.

Minerals	No of fortified foods, by micronutrient (% of the total sample by food type)										
	TOTAL*	Bars	Biscuits	Bread	Breakfast cereals	Fruit drinks	Milk/dairy drinks	Milk substitutes	Plant-based meat analogues	Yogurt/dairy dessert substitutes	Yogurts/fermented milk
Calcium	307 (7.1)	21 (7.8)	39 (6.1)	11 (3.1)	21 (5)	1 (0.4)	47 (11.6)	121 (36)	3 (1.1)	35 (24.8)	8 (1)
Chloride	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.4)	0 (0)	0 (0)
Copper	4 (0.1)	4 (1.5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dairy mineral salts	11 (0.3)	1 (0.4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	10 (1.2)
Iodine	18 (0.4)	2 (0.7)	0 (0)	9 (2.6)	3 (0.7)	0 (0)	0 (0)	3 (0.9)	1 (0.4)	0 (0)	0 (0)
Iron	158 (3.7)	21 (7.8)	36 (5.6)	4 (1.1)	63 (14.9)	0 (0)	5 (1.2)	1 (0.3)	20 (7.1)	0 (0)	8 (1)
Magnesium	26 (0.6)	12 (4.5)	9 (1.4)	0 (0)	0 (0)	0 (0)	5 (1.2)	0 (0)	0 (0)	0 (0)	0 (0)
Manganese	6 (0.1)	6 (2.2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Phosphorus	124 (2.9)	4 (1.5)	5 (0.8)	0 (0)	4 (0.9)	0 (0)	21 (5.2)	52 (15.5)	14 (5)	23 (16.3)	1 (0.1)
Potassium	22 (0.5)	8 (3)	0 (0)	8 (2.3)	1 (0.2)	0 (0)	1 (0.2)	3 (0.9)	0 (0)	0 (0)	1 (0.1)
Selenium	3 (0.1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.4)	1 (0.2)	0 (0)	0 (0)	0 (0)	1 (0.1)
Zinc	34 (0.8)	6 (2.2)	0 (0)	0 (0)	2 (0.5)	3 (1.2)	13 (3.2)	1 (0.3)	0 (0)	0 (0)	9 (1.1)

*: values in brackets in this column are represented in Figure 1A

Table S2 (cont)

Items with added minerals or vitamins, by food type and micronutrient.

Vitamins	No of fortified foods, by micronutrient (% of the total sample by food type)										
	TOTAL**	Bars	Biscuits	Bread	Breakfast cereals	Fruit drinks	Milk/dairy drinks	Milk substitutes	Plant-based meat analogues	Yogurt/dairy dessert substitutes	Yogurts/fermented milk
A	217 (5)	15 (5.6)	19 (3)	0 (0)	0 (0)	61 (24.2)	97 (24)	23 (6.8)	0 (0)	0 (0)	2 (0.2)
B (general)	2 (0)	2 (0.7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
B1	167 (3.9)	34 (12.7)	37 (5.8)	5 (1.4)	62 (14.6)	5 (2)	12 (3)	5 (1.5)	1 (0.4)	0 (0)	6 (0.7)
B2	184 (4.3)	38 (14.2)	31 (4.8)	0 (0)	70 (16.5)	2 (0.8)	9 (2.2)	25 (7.4)	0 (0)	9 (6.4)	0 (0)
B3	169 (3.9)	42 (15.7)	36 (5.6)	5 (1.4)	67 (15.8)	5 (2)	9 (2.2)	4 (1.2)	1 (0.4)	0 (0)	0 (0)
B5	95 (2.2)	31 (11.6)	17 (2.7)	0 (0)	32 (7.5)	5 (2)	9 (2.2)	0 (0)	0 (0)	0 (0)	1 (0.1)
B6	228 (5.3)	44 (16.4)	39 (6.1)	0 (0)	63 (14.9)	19 (7.5)	29 (7.2)	4 (1.2)	0 (0)	0 (0)	30 (3.7)
B8	41 (1)	21 (7.8)	1 (0.2)	0 (0)	4 (0.9)	6 (2.4)	9 (2.2)	0 (0)	0 (0)	0 (0)	0 (0)
B9	216 (5)	38 (14.2)	27 (4.2)	0 (0)	65 (15.3)	4 (1.6)	70 (17.3)	4 (1.2)	0 (0)	0 (0)	8 (1)
B12	198 (4.6)	30 (11.2)	12 (1.9)	0 (0)	48 (11.3)	6 (2.4)	21 (5.2)	38 (11.3)	27 (9.6)	11 (7.8)	5 (0.6)
C	143 (3.3)	23 (8.6)	0 (0)	1 (0.3)	1 (0.2)	98 (38.9)	14 (3.5)	4 (1.2)	0 (0)	0 (0)	2 (0.2)
D	359 (8.3)	22 (8.2)	29 (4.5)	0 (0)	35 (8.3)	10 (4)	115 (28.4)	78 (23.2)	0 (0)	13 (9.2)	57 (7.1)
E	218 (5.1)	29 (10.8)	11 (1.7)	0 (0)	10 (2.4)	67 (26.6)	82 (20.2)	17 (5.1)	0 (0)	0 (0)	2 (0.2)
K	14 (0.3)	2 (0.7)	0 (0)	0 (0)	0 (0)	0 (0)	12 (3)	0 (0)	0 (0)	0 (0)	0 (0)

**: values in brackets in this column are represented in Figure 1B

Table S3

Energy and nutrient density values in 100 g.

Food type	Fortified	Energy (kcal)			Protein (g)			Carbohydrates (g)			Sugar (g)		
		n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value
Breakfast cereals –	No	251	394 (374; 437)	< 0.01*	251	9.2 (7.8; 11)	0.056	251	65 (60.1; 74)	< 0.001*	250	17 (11; 22)	< 0.001*
with added ingredients	Yes	75	385 (375; 394)		75	8.4 (7.2; 10)		75	75 (68; 79.9)		75	22 (16; 26)	

n: Foods with data. IR: interquartile range; * statistically significant differences according to p < 0.05.

Table S3 (cont)

Energy and nutrient density values in 100 g.

Food types	Fortified	Total fat (g)			Saturated fat (g)			Fibre (g)			Sodium (mg)		
		n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value	n	Median (IR)	*p*-value
Breakfast cereals –	No	251	8.4 (3.6; 15)	< 0.001*	250	1.8 (0.8; 3.5)	< 0.001*	237	7.2 (5.1; 9)	0.069	245	84 (14; 236)	< 0.001*
with added ingredients	Yes	75	3.5 (1.9; 7)		75	0.9 (0.5; 2.2)		74	5.5 (4.1; 8.5)		75	264 (150; 342)	

n: Foods with data. IR: interquartile range; * statistically significant differences according to p < 0.05.