Current Research in Food Science 9 (2024) 100796

Contents lists available at ScienceDirect

Current Research in Food Science

journal homepage: www.sciencedirect.com/journal/current-research-in-food-science

Nutrition classification schemes for plant-based meat analogues: Drivers to assess nutritional quality and identity profile

Nathalia Tarossi Locatelli [a,b], Grace Fen Ning Chen [a], Mariana Frazão Batista [a,b], Júnior Mendes Furlan [c], Roger Wagner [d], Daniel Henrique Bandoni [a], Veridiana Vera de Rosso [a,*]

[a] Food Labeling Observatory, Nutrition and Food Service Research Center (CPPNAC), Federal University of São Paulo (UNIFESP), Santos, SP, Brazil
[b] Graduate Program in Nutrition, Federal University of São Paulo (UNIFESP), São Paulo, Brazil
[c] Federal University of Pampa (UNIPAMPA), Itaqui, Rio Grande do Sul, Brazil
[d] Department of Technology and Food Science, Federal University of Santa Maria (UFSM), Santa Maria, Rio Grande do Sul, Brazil

ARTICLE INFO

Handling editor: Yeonhwa Park

ABSTRACT

Changes in dietary patterns promoted by the emergence of alternative food systems are becoming increasingly common. The decrease in the consumption of animal-derived products promoted exponential growth in plant-based product demand and, consequently, the availability of several meat analogues for this consumer market. Plant-based meat analogues (PBMAs) were developed to mimic the physical and sensory characteristics of meats and their derivatives. Therefore, the composition of these products has been studied in some countries as an attempt to evaluate their nutritional quality in comparison with that of traditional meat products. The main aim of this study was to employ different Nutrition Classification Schemes (NCSs) to assess the nutritional quality of plant-based meat and to discuss the application of one or more NCSs in defining the identity and quality profile of these foods. Five NCSs were used: three nutrient-based (Nutri-Score; Nutrient Profiling Model (NPM) from Brazil; NPM from PAHO); one food-based (NOVA classification); and one hybrid (Plant-Based Nutrient Profile Model). The nutritional composition and ingredients were collected from labels of 349 PBMAs; 117 were classified as burgers, and 182 products employed soy as the main protein ingredient. The use of different NCSs is strategic for PBMAs' nutritional quality evaluation, and the Nutri-Score was able to show the effectiveness of differentiating products as having poor nutritional quality. In this way, the employment of NPM from Brazil is recommended as a driver for PBMAs choices, especially due to the excellent agreement between the Nutri-Score and NPM from Brazil for burgers.

1. Introduction

The "plant-based diet" is identified as the main global consumption trend in nutritional and functional terms (Sloan, 2021). Despite the focus on foods derived from plant sources such as fruits, vegetables, grains, potatoes, legumes, nuts, and seeds, the absence of food of animal origin is not mandatory. This diet profile can include various types and amounts of animal food products, resulting in a spectrum of abstention from animal products ranging from veganism to semivegetarianism. Several motivations for plant-based adoptive diets often include a combination of ethical, environmental, health, and social considerations. The environmental impacts of meat production, including deforestation (zu Ermgassen et al., 2020), greenhouse gas emissions (Boehm et al., 2019; Yip et al., 2023), and water usage (Gerbens-Leenes et al., 2013) are significant motivators for the adoption of plant-based diets.

The most frequently cited reason for the reduction in meat consumption is linked to health, well-being and weight loss. Red meat and processed meat intake are associated with a greater risk of chronic noncommunicable diseases (Chung et al., 2021), particularly cardiovascular disorders (Pan et al., 2022) and type 2 diabetes (Gu et al., 2023). In addition, the cost of meat can change the frequency of red meat consumption (Barnhill et al., 2022; Springmann et al., 2018), especially in developing countries. However, evidence regarding the epidemiologic profile of plant-based diet followers is poor. In general, young female people are more motivated to reduce or eliminate food

* Corresponding author. Nutrition and Food Service Research Center, Universidade Federal de São Paulo (UNIFESP), Rua Silva Jardim 136, 11015–020, Santos, Brazil.

E-mail address: veridiana.rosso@unifesp.br (V.V. de Rosso).

https://doi.org/10.1016/j.crfs.2024.100796
Received 8 May 2024; Received in revised form 10 June 2024; Accepted 17 June 2024
Available online 19 June 2024

from animal products in their diet (Gómez-Luciano et al., 2019).

While there are various motivations for replacing a meat diet, there are also several challenges and limitations associated with adopting a plant-based diet. First, some individuals may find it challenging to adapt to the taste and texture of plant-based alternatives, especially if they have grown up with a diet centered around animal products. Another important factor is the need to learn new culinary abilities for dish preparation, which can be time-consuming and impractical.

The plant-based food market has evolved beyond traditional options such as veggie burgers and tofu. Currently, there is a wide array of plant-based products that mimic the taste and texture of animal-derived foods. The market is diversifying to cater to various dietary preferences and cultural tastes. Considering the rapid expansion of these foods, numerous questions have arisen concerning their nutritional content and health benefits. Are Vegan Alternatives to Meat Products Healthy (Romão et al., 2022)? and Are plant-based alternatives healthier (de las Heras-Delgado et al., 2023)? are frequently asked questions by researchers and consumers around the world. To address these questions, several studies have examined the nutritional profiles of plant-based foods designed as meat alternatives. These studies often rely on information sourced from nutritional facts on labels from numerous countries (Alessandrini et al., 2021; Bryngelsson et al., 2022; Curtain and Grafenauer, 2019; de las Heras-Delgado et al., 2023; Farsi et al., 2022; Harnack et al., 2021; Ložnjak Švarc et al., 2022; Rizzolo-Brime et al., 2023; Rodríguez-Martín et al., 2023; Romão et al., 2022, 2023; Tonheim et al., 2022), particularly in more advanced economies recognized for their elevated per capita meat consumption.

Nevertheless, conducting a unidimensional evaluation based solely on nutrient levels might introduce biases to a profoundly intricate matter. Additionally, employing the term "ultra-processed", as per the NOVA classification, equates plant-based foods with their meat analogues, amplifying uncertainties about categorizing healthy foods into groups linked to the onset of chronic diseases (Derbyshire, 2019; Duque-Estrada and Petersen, 2023; Fitzgerald, 2023; Hallinan et al., 2021; Petrus et al., 2021).

In this context, in the present study, we utilized five distinct nutritional classification schemes (NCSs) to assess the nutritional quality of plant-based meat analogues (PBMAs) and to examine the agreement between the classifications established by these various schemes. An NCS is defined as a method developed to classify individual foods or food groups in relation to their claimed health status (Dickie et al., 2022).

While there are varying perspectives on the concepts and technical applications of NCSs, their utilization is becoming more common, notwithstanding diverse conceptual alignments. In the first case, nutrient-based NCSs are informed by evidence on the effects of specific nutrients and food components on metabolic processes or health outcomes. The Nutrient Profiling Models (NPMs) developed for Front of Packing Labeling (FOPL) include nutrient-based NCSs (Dickie et al., 2022), such as the Nutri-Score (France, Ministry of Health and Prevention, 2017), and different warning label systems, e.g., the Chilean and Brazilian (Batista et al., 2022; Brazil, Ministry of Health and National Health Surveillance Agency, 2020a NPMs. Food-based NCSs are the second type of NCS and are informed by evidence of a food's matrix or composition and associations with health outcomes. The NOVA classification system (Brazil, Ministry of Health, 2014) is the most commonly applied food-based NCS. Finally, diet-based NCSs are informed by evidence on dietary patterns and consider the concepts of variety, adequacy, and moderation, e.g., the Diet Quality Index International.

Although the evidence regarding the accuracy of nutrient-based and food-based nutrient schemes in correctly classifying food products based on nutritional quality and enabling extrapolation to determine their degree of healthiness is limited, this is primarily due to the absence of a standardized benchmark against which the validity of NCS can be assessed (Dickie et al., 2022). However, studies assessing the nutritional quality of plant-based foods using NCSs are still limited, and studies often apply only one NCS and fail to evaluate the agreement between different schemes.

The primary objectives of this study were to employ different NCSs to assess the nutritional quality of plant-based foods and to discuss the application of one or more NCSs in defining the identity and quality profile of these foods. This approach aims to ensure that the nutritional characteristics of products that resemble those of meat are met. To fulfill the second objective, a comparative analysis of the nutritional profiles of PBMAs sold in Brazil with those of PBMAs sold in other countries was conducted employing a metanalytic strategy.

2. Materials and methods

In this cross-sectional, descriptive, and quantitative study, we used information collected from food labels focused on plant-based meat analogues sold in Brazil. The data were collected between July 2022 and June 2023 by trained researchers from the Food Labeling Observatory using a standardized protocol.

2.1. Store, product selection and labeling database construction

The selection of sales outlets was considered the largest retail companies in Brazil, and given the size of the country, a comprehensive search for labels was conducted across all five regions of the country to ensure nationwide representativeness of the products. Two stores were visited in each of the three largest retail chains. However, there were instances of brand repetition when the sampling focus was on the primary points of sale in various regions. Therefore, an active search for products was carried out at points of sale specialized in vegetarian/vegan food and in regional supermarket chains. All plant-based meat analogues found at the points of sale were selected. The selected plant-based meat products were designed not to contain any animal-based ingredients and were labeled with specific denominations such as "vegan", "vegetarian", "make only with plants", "100% vegetables", and "veggie", among others. Thus, labels from meat analogues of burgers, breaded products, kibbeh sausages, ham, mortadella, bacon, salami, fish, meatballs, kafta and meats were collected. For the sampling of animal (minced meat, shredded beef, chicken fillet, beef steak, among others) meat products, we used the same protocol.

All sides of the label were photographed using a camera (cell phones or tablets) to gather information related to the nutrition facts, list of ingredients, nutritional claims, commercial brand, company address, package size, and other information presented on the label. In addition, data were collected from the GPS (Global Positioning System) of the sale's point and product prize. All information was registered on the Brazilian Food Labeling Database using its barcode, thus preventing duplicates of the sample.

2.2. Plant-based meat analogues and meat product classification

The plant-based meat analogues and meat products were classified according to sales category (burger, breaded, kibbeh, sausages and cured meats, meatballs, meat (minced meat, shredded beef, chicken fillet, beef steak, among others). In addition, the PBMA products were categorized according to their main ingredients, such as proteins and fatty acids (Table 1).

Based on the groups established, a descriptive statistical analysis of the products' nutritional composition data was initially carried out, including energy value (kcal), carbohydrates (g), proteins (g), total fats (g), saturated fats (g), trans fats (g), fiber (g) and sodium (mg) expressed to the serving size of 100 g. Other nonmandatory declaration nutrients were also registered, such as vitamins and minerals.

For the descriptive analyses, we first tested the normality of the continuous variables through the Shapiro–Wilk test. Once nonnormal distributions were confirmed, we then performed the Mann–Whitney test to assess differences in the median for all nutrients between PBMA and meat products with significance levels set at a p value of <0.05. The

Table 1
Characterization of plant-based meat analogues and meat products, grouped according to the sales category and the main protein and main fat source.

	Plant-based meat analogues	Meat products
Sales category	n (%)	n (%)
Burger	117 (33.5)	51 (14.5)
Breaded	47 (13.5)	39 (11.1)
Kibbeh	27 (7.7)	5 (1.4)
Cured meat[a]	56 (16.1)	195 (55.6)
Meatball	30 (8.6)	7 (2.0)
Meat[b]	72 (20.6)	54 (15.4)
Main protein source	**n (%)**	
Soy	182 (52.2)	–
Pea	57 (16.3)	–
Other[c]	67 (19.2)	–
None	43 (12.3)	–
Main fat source	**n (%)**	
Unsaturated FA	193 (55.3)	–
Saturated FA	81 (23.2)	–
None	75 (21.5)	–
Total	**349 (100.0)**	**351 (100.0)**

FA: Fatty acids.
[a] Cured meat: sausage, ham, salami, among others.
[b] Meat: minced meat, shredded beef, chicken fillet, beef steak, among others.
[c] Other: chickpeas, lentils, beans, wheat, gluten, rice, mix (soy, peas and chickpeas).

variables are expressed through descriptive statistics using medians, minimums and maximum.

The ingredients listed from PBMAs were compiled to collect the additives used in these products, followed by identification of their technological function according to current Brazilian legislation (Brazil, Ministry of Health, National Health Surveillance Agency, 2022). Information about nutritional claims was also collected on the PBMAs' labels.

2.3. Principal component analysis (PCA) and cluster formation

For principal component analysis, the composition data (energy value, carbohydrates, proteins, total fats, saturated fats, *trans* fats, fiber and sodium) compiled from all PBMAs labels were used. The principal components were obtained from a linear combination of the original variables that explained the most variance. To define the number of principal components retained, we used 80% of the total variance of the data, followed by orthogonal rotation (Varimax), and 0.3 was the minimum saturation of each factor. To define the clusters, k-medians from nutritional composition and PCA factors were used. PCA revealed linear combinations of nutritional components that separate different clusters corresponding to different PBMAs.

2.4. Nutrition classification schemes (NCSs)

Five distinct nutritional classification schemes (NCSs) were used to assess the nutritional quality of the PBMA and meat products. We employed a nutrient-based NCS developed for Front of Packing Labeling (FOPL) proposed in Brazil (Brazil, Ministry of Health, National Health Surveillance Agency, 2020a; Brazil, Ministry of Health, National Health Surveillance Agency, 2020b), an NPM proposed by the Pan-American Health Organization (PAHO) (Pan American Health Organization, 2016), and the Nutri-Score (France, Ministry of Health and Prevention, 2017). In addition, the NOVA classification system (Brazil, Ministry of Health, 2014), which categorizes foods into 4 groups based on their nature, extent, and purpose of processing, was employed. In addition, we proposed one NCS for plant-based foods grounded in the hybrid use of the Nutri-Score and NOVA classification.

1. **NPM proposed for FOPL in Brazil:** We applied the limits established for critical nutrients for saturated fat and sodium (Brazil et al., 2020b). We classified foods as having a good nutritional profile when the levels of saturated fat and sodium did not exceed the established limits and a poor nutritional profile when at least one of the limits was exceeded (added sugar limit: 15 g/100 g; saturated fat limit: 6.0 g/100 g; sodium limit: 600 mg/100 g).
2. **NPM proposed for PAHO**: The nutrient profile established by the PAHO/WHO - World Health Organization is based on intake targets for critical nutrients (Pan American Health Organization, 2016). The following limits were applied to define foods with poor nutritional profiles: ≥1 mg of sodium per kcal; ≥10% of total energy from free sugars; ≥30% of total energy from total fats; ≥10% of total energy from saturated fat; ≥1% of total energy from *trans* fat; and the presence of sweeteners in the list of ingredients. A food that did not exceed at least one of these limits was classified as having a good nutritional profile. The nutritional facts adopted in Brazil did not include the free sugars declaration; in this way, we estimated the amount of free sugar using the method described by (Scapin et al., 2021) and considered free sugar equivalent to the amount of added sugars.
3. **NPM proposed in the Nutri-Score for FOPL:** We applied the new Nutri-Score algorithm based on the nutritional profile developed by the French Ministry of Health (France, Ministry of Health and Prevention, 2017) to each of the foods studied. A classification was assigned to the food, ranging from five categories associated with letters A (best nutritional quality) to E (worst nutritional quality). We considered the foods classified as having a good nutritional profile to be those classified as A, B and C and those classified as having a poor nutritional profile to be those classified as D and E.
4. **NOVA classification system**: Foods were classified according to the degree of processing, following the criteria adopted by the Food Guide for the Brazilian Population (Brazil, Ministry of Health, 2014). The foods were categorized as ultra-processed or non-ultra-processed (including processed and minimally processed).
5. **NPM for Plant-based foods (NPMPB):** The foods were classified into three categories of nutritional quality: good nutritional quality (foods classified as A, B or C by the Nutri-Score and not ultra-processed), intermediate nutritional quality (classified as A, B or C by the Nutri-Score and ultra-processed) and low nutritional quality (foods classified as D or E by the Nutri-Score regardless of the level of processing).

The comparison of the degree of strictness of each NCS was carried out by the number and proportion (percentages and 95% CIs) of PBMA and meat products classified as having poor nutritional profiles. Overall, by sales category and for PBMA, the classification was evaluated according to the main protein and fat source groups through the number and proportion of the PMBAs and meat products that were classified similarly or differently between any two NCSs, and Cohen's kappa statistics were obtained. Agreement was interpreted as follows: 0.01–0.20 – slight; 0.21–0.40 – fair; 0.41–0.60 – moderate; 0.61–0.80 – substantial; and 0.81–1.00 – excellent.

All analyses were performed using Stata/SE software (version 14.0, Stata Corp, College Station, TX).

2.5. Comparison of the nutritional composition of PBMA sales in Brazil with those of other countries

Several studies have investigated the nutritional composition of PBMA in different countries. We selected eight studies in which the composition data were expressed as the median (minimum and maximum) for comparison with the results of this study. For this analysis, we used a meta-analytical approach to pool the results of the independent studies and compute a summary measure. Specifically, we used the weighted difference between the medians, considering measurements on the same scale for the analysis, and the median of the study-specific estimates as the point estimate of the pooled outcome measure. We used the metamedian package in R for random effect modeling, considering the median, minimum, and maximum values and sample size.

3. Results and discussion

3.1. Plant-based meat analogues and the nutritional composition of meat products

The nutritional composition and ingredients were collected from labels of 349 plant-based meat analogues and 351 meat products available on the Brazilian market. We grouped these foods according to their sales category, and for PBMAs, an additional classification was used based on the main ingredient, such as a source of proteins and fatty acids (Table 1). A total of 33.5% of PBMAs were classified as burgers, 52.1% employed soy as the main protein ingredient, and 55.3% used unsaturated fatty acids as their main fat source. In 12.3% (n = 43) of PBMAs, an ingredient considered a source of protein was not identified, and in 21.5% (n = 75) of PBMAs, an ingredient considered a source of fatty acids was not identified. Table 2 shows the median nutritional composition of PBMAs and meat products (minimum; maximum), and Fig. 1 compares the nutrient levels in those products.

The plant-based meat analogues sold in Brazil showed important variation in nutritional composition, even when grouped according to their sales category. The protein content in plant-based burgers was significantly lower than that in meat burgers ($p < 0.001$), and the same trend was observed for breaded ($p < 0.001$) and cured meats ($p < 0.001$). For other categories, no difference was observed in the protein content (kibbeh, $p = 0.090$; meat, $p = 0.280$ and meatballs, $p = 0.900$) in relation to meat products (Fig. 1A). The soy and its derivatives (concentrated and isolated protein) are the main protein sources employed in PBMAs due to their gelling, emulsification, fat absorption

Table 2
Nutritional composition of plant-based meat analogues and meat products, grouped according to sales category, main protein source and fat source. Values presented as median (minimum; maximum).

Category	N	Nutritional composition (expressed in 100 g) Energy value (Kcal)	Carbohydrates (g)	Proteins (g)	Total fats (g)	Saturated fats (g)	*Trans* fats (g)	Fiber (g)	Sodium (mg)
Plant-based meat analogues									
Burger	117	193 (54; 516)	16.0 (1.4; 72.0)	12.2 (1.3; 53.7)	7.5 (0.0; 20.0)	1.4 (0.0; 17.5)	0.0 (0.0; 1.3)	5.2 (0.0; 14.1)	376 (15; 1966)
Breaded	47	213 (22; 299)	21.0 (1.4; 37.0)	10.0 (1.4; 22.0)	8.0 (0.1; 21.5)	1.3 (0.0; 9.5)	0.0 (0.0; 0.0)	5.0 (0.0; 13.8)	463 (1.0; 1040)
Kibbeh	27	162 (109; 380)	25.0 (9.8; 58.0)	7.6 (3.4; 22.0)	4.8 (0.0; 11.5)	0.9 (0.0; 6.1)	0.0 (0.0; 0.1)	4.4 (0; 0; 15.2)	388 (118; 695)
Cured meat	56	186 (75; 753)	8.2 (1.2; 51.0)	14.4 (1.8; 51.6)	10.7 (0.6; 73.3)	1.0 (0.0; 7.8)	0.0 (0.0; 1.9)	4.0 (0; 0; 15.5)	588 (0.0; 1950)
Meatballs	30	177 (99; 293)	12.5 (0.0; 39.0)	13.2 (1.0: 24.0)	6.4 (0.0; 20.0)	1.2 (0.0; 9.8)	0.0 (0.0; 0.1)	5.7 (0.5; 10.5)	350 (127; 803)
Meat	72	148 (44; 744)	9.9 (0.0; 52.0)	13.7 (1.3; 52.0)	4.9 (0.0; 18.0)	0.5 (0.0; 13.1)	0.0 (0.0; 4.1)	4.6 (0.0; 38.0)	438 (0.0; 1541)
Total	**349**	**186 (22; 744)**	**14 (0; 72)**	**12.2 (1; 53.7)**	**6.9 (0; 73.3)**	**1 (0; 17.5)**	**0 (0; 4.1)**	**4.6 (0; 38)**	**416 (0; 1966)**
Main protein source									
Soy	182	192 (44; 516)	11.0 (0.0; 72.0)	14.4 (4.2; 52.0)	9.1 (0.0; 20.0)	1.4 (0.0; 13.1)	0.0 (0.0; 4.1)	4.8 (0.0; 38.0)	528 (0.0; 1966)
Pea	57	208 (136; 352)	11.0 (0.0; 32.0)	12.5 (4.5; 53.7)	10.9 (0.8; 21.5)	3.8 (0.0; 17.5)	0.0 (0.0; 0.0)	4.7 (0.0; 12.0)	416 (68; 1315)
Other	67	152 (54; 323)	20.0 (5.0; 46.0)	7.6 (1.3; 28.0)	3.0 (0.0; 13.3)	0.4 (0.0; 4.3)	0.0 (0.0; 1.3)	5.0 (0.0; 12.2)	319 (15; 836)
None	43	144 (22; 753)	23.0 (1.4; 52.0)	3.4 (1.0; 10.3)	4.3 (0.0; 73.3)	0.3 (0.0; 6.0)	0.0 (0.0; 0.0)	2.6 (0.0; 15.2)	285 (0.0; 1541)
Main fat source									
Unsaturated FA	193	186 (61; 516)	15.0 (0.0; 55.0)	12.2 (1.0; 51.5)	7.9 (0.0; 21.5)	1.0 (0.0; 17.5)	0.0 (0.0; 4.1)	4.8 (0.0; 17.5)	431 (31; 1966)
Saturated FA	81	193 (54; 387)	9.8 (1.4; 58.0)	12.5 (1.3; 34.4)	10.3 (0.6; 20.0)	4.7 (0.0; 13.1)	0.0 (0.0; 0.1)	4.6 (0.0; 13.4)	430 (21; 1583)
None	75	159 (22; 753)	20.0 (0.4; 72.0)	10.0 (1.4; 53.7)	1.6 (0.0; 73.3)	0.2 (0.0; 6.0)	0.0 (0.0; 0.2)	4.4 (0.0; 38.0)	328 (0.0; 1541)
Meat products									
Burger	51	219 (101; 281)	1.2 (0; 13.8)	16.2 (12.0; 27.5)	15.0 (2.8; 22.5)	7.0 (1; 12.5)	0.0 (0.0; 0.8)	0.5 (0.0; 21.5)	552 (49; 867)
Breaded	39	217 (0; 471)	16.1 (7.7; 21.3)	12.3 (7.7; 19.2)	11.5 (1.3; 16.2)	3.5 (0.3; 10)	0.0 (0.0; 0.5)	1.2 (0.0; 7.2)	500 (352; 671)
Kibbeh	5	200 (141; 264)	11.1 (5.1; 28.8)	12.1 (8.5; 13.8)	11.6 (1.6; 15.2)	5.5 (0.5; 7)	0.0 (0.0; 0.5)	1.6 (0.0; 4.8)	674 (581; 732)
Cured meat	195	238 (73; 820)	1.0 (0.0; 10.7)	16.8 (5.5; 103.3)	16.8 (0.0; 43.6)	5.8 (0; 42)	0.0 (0.0; 0.4)	0.0 (0.0; 7.0)	1128 (60; 5500)
Meatballs	7	194 (119; 400)	3.4 (0; 7.5)	13.8 (8.6; 16.3)	8.8 (6.0; 18.8)	4.1 (1; 8.9)	0.0 (0.0; 0.8)	0.9 (0.0; 1.8)	592 (280; 702)
Meat	54	160 (75; 400)	0.0 (0.0; 42)	16.0 (1.8; 46)	9.1 (0.6; 30)	2.9 (0; 11)	0.0 (0.0; 0.7)	0.0 (0.0; 2.4)	580 (43; 7723)
Total	**351**	**217 (0.0; 820)**	**1.2 (0.0; 42)**	**16.0 (1.8; 103.3)**	**14.0 (0; 43.6)**	**5.0 (0; 42)**	**0.0 (0.0; 8)**	**0.0 (0; 21.2)**	**836 (43; 7723)**

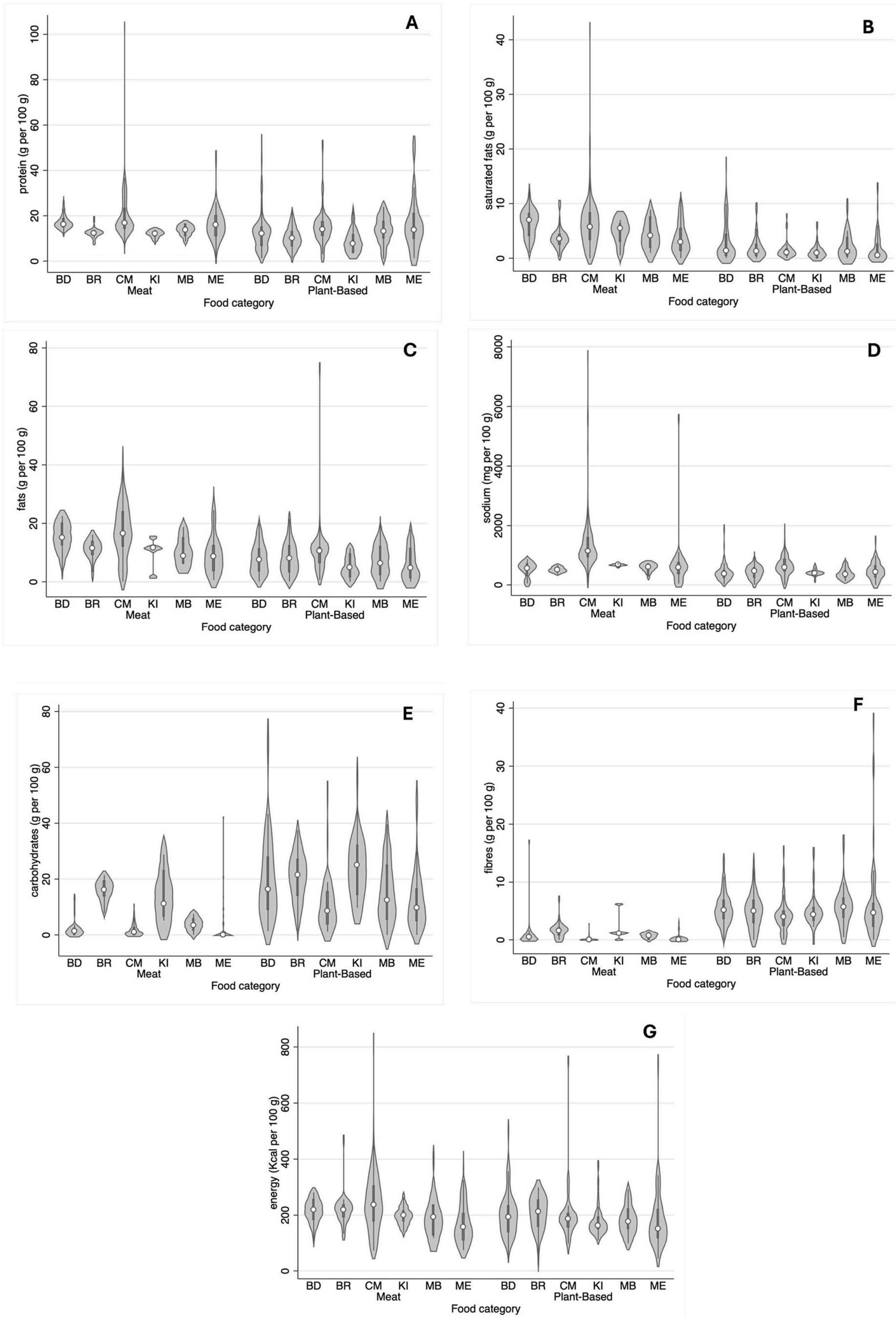

Fig. 1. Nutritional composition comparison between plant-based meat analogues and meat products, according to different sales categories. A) proteins, B) saturated fats, C) total fat, D) sodium, E) carbohydrates; F) fibers, G) energy value. BD: Breaded, BR: Burger, CM: Cured meat, KI: Kibbeh, MB: Meatball, ME: Meat.

and water-holding capacities (Ahmad et al., 2022). Furthermore, Brazil is the largest soy producer in the world, reaching a production of 160 million tons in 2023 (Brazil, National Supply Company, 2024). The PBMAs produced with soy had a greater protein content than those produced with other protein sources ($p < 0.001$).

The median saturated fat content for all PBMAs was 5 times lower than that for meat products ($p < 0.001$) (Fig. 1B). Similar behavior was observed for the total fat median, and the total fat content for all PBMAs was 2 times lower than that for meat products, except for meatballs (Fig. 1C). The median total fat content of plant-based meatballs did not differ from that of traditional meatballs ($p = 0.100$). The majority of the PBMAs (55%) used soy and sunflower oil as their main source of fat, while 23% used coconut oil or unspecified vegetable fat as their main source. Moreover, 22% did not present any source of lipids in the ingredient list. Similarly, the sodium content in PBMA was significantly lower than that in meat products (burgers, $p < 0.001$; breaded, $p = 0.05$; kibbeh, $p < 0.001$; cured meat, <0.001; meatballs, $p = 0.05$; meats, $p = 0.03$) (Fig. 1D). On the other hand, the carbohydrate (Fig. 1E) and fiber (Fig. 1F) contents of PBMAs were significantly greater for all categories ($p < 0.001$), except for the kibbeh category, in which the carbohydrate content did not differ ($p = 0.08$). For the burgers and cured meat categories, the energy value was significantly greater for PBMAs than for the respective meat products ($p = 0.002$ and $p < 0.001$, respectively) (Fig. 1G). In other categories, no difference was observed (breaded, $p = 0.910$; kibbeh, $p = 0.241$; meatballs, $p = 0.663$; meats, $p = 0.713$).

To overcome the heterogeneity of nutritional composition data for PBMAs sold in Brazil, we performed a principal component analysis (PCA) to explain the effect of variance of nutrients independently on component formation. Four main components were generated, which together explained 86% of the variance in nutritional composition. Table 1S shows that each component appears with to have a respective saturation in relation to the extracted factors. It is possible to observe that component 1 can be explained by total fat, saturated fat and energy. Component 2 is strongly explained by the fiber content and has a lower degree of saturation due to the protein content. Component 3 is characterized by a high carbohydrate content and low energy value, and component 4 is characterized by a high sodium content. In this way, based on the PCA results, the PBMAs were grouped according to their similarity to each component. The nutritional composition of the PBMAs classified according to the four principal components is shown in Table 3. Most products ($n = 144$) were classified as component 3 (carbohydrates and energy value), which is not expected from PBMAs. In addition, the protein content was shown to guide cluster formation, and the influence of fiber ($n = 76$) and sodium content ($n = 77$) was evident and more significant for components 2 and 4. It is important to consider that in the PCA, there is a linear combination of all variables, so there are PBMAs that have characteristics or two or more components. Thus, any classification adopted will have some level of arbitrariness, and a heterogeneous nutritional composition increases the intersection between factors when defining the groups, which was proven when it was observed that the factors generated in PCA do not adhere to a normal distribution.

In this way, it was observed during label collection for this study that the brands with the largest share in the plant-based market carried out at least one reformulation of their products. These findings demonstrate that the market is constantly trying to meet consumer demands, promoting the supply of healthier foods.

3.2. Plant-based meat analogues nutritional composition comparison between products sold in Brazil and those sold in other countries

The comparison between the nutritional composition of PBMAs sold in Brazil and that of PBMAs marketed in other countries was carried out using a meta-analytic approach to aggregate the results of independent studies to combine them into a summary measure (Table 4). We selected eight studies in which the composition data were expressed as medians (minimums and maximum) for comparison with the results of this study. Other studies that employed results expressed as the mean ± standard deviation were considered ineligible for this analysis. Table 4 presents the nutritional composition of 1775 PBMAs identified in three studies from Spain (de las Heras-Delgado et al., 2023; Gasparre et al., 2022; Rizzolo-Brime et al., 2023) and one study from each of the following countries: Italy (Cutroneo et al., 2022), Brazil (Romão et al., 2022), Sweden (Bryngelsson et al., 2022), the United States (Harnack et al., 2021) and Norway (Tonheim et al., 2022).

The overall energy, protein, total fat, and sodium levels were obtained using the weighted difference between the medians from each study, considering measurements from the same scale. Therefore, the number of PBMAs included in each study and the homogeneity of the nutrient composition contributed to the weight of the overall measure. In the protein level comparison, the greatest weight in defining the overall results was fulfilled by PBMAs from study eight (Tonheim et al., 2022) and study seven (Harnack et al., 2021), with weights of 29.94 and 27.53%, respectively. Although the median protein content in this study (12.20 g/100 g) was similar to that overall (12.52 g/100 g), the homogeneity, represented by the minimum and maximum values, was lower than that overall (9.81 and 15.23 g/100 g). Consequently, in terms of protein content, PBMAs sold in Brazil are different from those marketed in other countries, and there is great variation in these values between studies. Similar behavior was observed for the levels of total fat, sodium, and energy, since the study eight employed PBMAs from Norway (Tonheim et al., 2022) and showed high weights for all components (37.08% for total fat, 41.17% for sodium and 37.54% for energy).

In terms of total fat, the median value of 6.60 g/100 g observed in this study was lower than the overall median (9.53 g/100 g). In addition, the minimum and maximum values presented a wide range (0.00 and 73.30 g/100 g, respectively) in relation to the overall values. Therefore, most PBMAs sold in Brazil are different from those marketed in other

Table 3
Nutritional composition of plant-based meat analogues, grouped according to Principal Component Analysis (PCA). Values presented as median (minimum; maximum).

Component/Energy and nutrient[a]	1			2			3			4		
	Total fats, saturated fats, energy value ($n = 52$; 14.8%)			Fiber and proteins ($n = 76$; 21.8%)			Carbohydrates and energy value ($n = 144$; 41.3%)			Sodium and proteins ($n = 77$; 22.0%)		
	Median	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Median**	**Min.**	**Max.**
Energy value (kcal)	198.7[a]	133.3	278.0	160.6[b]	52.0	267.5	153.5[c]	22.4	753.3	245[d]	99	516.7
Proteins (g)	14.0[a]	9.7	19.5	16.2[b]	4.9	50.0	6.7[c]	1.0	23.13	15.0[d]	1.8	53.7
Total fats (g)	12.0[a]	1.60	19.0	6.8[b]	0.0	14.9	3.5[c]	0.0	73.3	11.2[d]	0.0	20.0
Saturated fats (g)	7.6[a]	0.0	17.5	0.9[b]	0.0	5.75	0.4[c]	0.0	6.0	2.0[d]	0.0	5.7
Carbohydrates (g)	7.9[a]	1.4	18.75	6.0[b]	0.4	41.07	22.0[c]	0.0	72.5	16.6[d]	0.0	55.0
Fibers (g)	4.5[a]	0.0	10.0	5.0[b]	0.0	38.0	4.3[c]	0.0	15.2	5.4[d]	0.0	17.0
Sodium (mg)	450[a]	222	1131	437[b]	31	790	279[c]	0.0	1541	642[d]	0.0	1967

$p < 0.05$ non-parametric Kruskal-Wallis test. Different letters on the same line indicate significant differences in medians.
[a] Values expressed in 100 g.

Table 4
Comparison of nutritional composition of plant-based meat analogues sold in Brazil with other countries, and the general effect of the median value. Values are expressed as median, minimum and maximum.

Variable	Energy (kcal/100g)				Protein (g/100g)				Total Fat (g/100g)				Sodium (mg/100g)			
Study	Median	Min	Max	% Weight	Median	Min	Max	% Weight	Median	Min	Max	% Weight	Median	Min	Max	% Weight
Results	186.00	22.00	753.00	2.63	12.20	1.00	53.70	4.54	6.60	0.00	73.30	3.49	416.00	0.00	1966.00	5.86
Study 1	200.50	12.00	454.00	4.35	14.00	0.70	54.00	4.49	10.00	0.10	47.00	5.46	480.00	0.00	6400.00	1.80
Study 2	201.50	119.00	400.00	6.85	15.75	3.60	55.47	4.62	9.55	0.50	25.10	10.40	560.00	0.00	1040.00	11.08
Study 3	211.00	134.00	252.00	16.31	12.80	6.80	29.20	10.69	–	–	–	–	480.00	46.00	880.00	13.82
Study 4	193.30	34.57	476.00	4.36	13.08	1.83	50.00	4.97	9.00	0.00	32.00	8.00	473.33	0.40	1296.67	8.89
Study 5	201.00	12.00	476.00	4.15	13.50	0.70	55.50	4.37	9.60	0.00	47.00	5.44	478.00	0.00	1628.00	7.08
Study 6	204.00	82.00	320.00	8.09	14.00	3.40	30.50	8.84	11.18	0.40	23.00	11.32	570.00	120.00	1240.00	10.29
Study 7	155.00	87.00	211.00	15.52	11.60	7.20	15.90	27.53	6.50	0.20	13.80	18.81	–	–	–	–
Study 8	201.50	169.50	220.50	37.74	13.00	8.30	16.30	29.94	10.20	8.10	15.00	37.08	600.00	440.00	720.00	41.17
Overall	197.32	176.35	218.29	100.00	12.52	9.81	15.23	100.00	9.53	6.74	12.33	100.00	576.39	455.73	697.06	100.00

Study 1 (de las Heras-Delgado et al., 2023); Study 2 ((Rizzolo-Brime et al., 2023); Study 3 (Cutroneo et al., 2022); Study 4 (Romão et al., 2022); Study 5 (Gasparre et al., 2022); Study 6 (Bryngelsson et al., 2022); Study 7 (Harnack et al., 2021); Study 8 (Tonheim et al., 2022).

countries, and they may have a total fat content significantly higher or lower than the overall median. The same behavior was observed for the sodium content and energy, in which the median values of 416 mg/g for sodium and 186 kcal/100 g were lower than the overall median values of 576 mg/100 g and 197.32 kcal/100 g for sodium and energy, respectively. However, in both cases, there was a wide range between the minimum and maximum values.

In general, the % weights for the overall measure obtained in this study were 2.63% for energy, 4.54% for protein, 3.49% for total fat, and 5.86% for sodium. This behavior shows the poor homogeneity of the nutrient composition in PBMAs sold in Brazil and the consistent difference in relation to other products marketed worldwide. This difference can be attributed to the absence of plant-based regulation in Brazil, especially in relation to nutritional quality and identity profile. On the other hand, the meat products market is extremely regulated, and the identity profile has recently been established and revised, especially regarding the minimum protein levels required for meat burgers (14%), kibbeh (11%), meatballs (12%), and ham (16%) (Brazil, Ministry of Agriculture, 2000; Brazil, Ministry of Agriculture, 2023a; Brazil, Ministry of Agriculture, 2023b). For PBMAs, the minimum protein quantity in each serving size could be equivalent to 20% of the recommended daily intake (RDI). In particular, in the burger case, a portion of 80 g should contain at least 10 g of protein.

3.3. Nutritional classification schemes applied to plant-based meat analogues and meat products

Nutritional classification schemes (NCSs) are important tools for evaluating the nutritional quality of foods and diets and can be used to develop dietary guidelines, public health policies and recommendations for food choices for consumers and dietary patterns for health professionals (Dickie et al., 2022; Fitzgerald, 2023). Most NCSs use the nutrient profile model applied to foods; however, NOVA classification proposes classifying food based on the degree of processing (Monteiro et al., 2019). Recently, a rapid review of scientific evidence about healthy and unhealthy food definitions revealed 70 different NCSs employing 387 nutrient profile models (Lee et al., 2019) and revealed several limitations when one scheme was applied individually. In addition, in another review published by the same research group, of the 387 nutrient profile models for application in government-led nutrition policies, 78 were included after the exclusion criteria were met, and 58% did not present information on validity testing (Labonté et al., 2018).

A promising NCSs that uses multiple definitions of healthy and unhealthy foods tends to be a mixture of food-based dietary guidelines and nutrient profile models, where nutrient cutoff points are applied to specific food categories (Lee et al., 2019). In this context, the desirable nutritional quality profile of PBMAs can be very useful for their use as a healthy food.

In this study, five different nutritional classification schemes were used to evaluate the nutritional quality of PBMAs (Table 5). According to the Nutri-Score, 79.65% of PBMAs were classified with A, B and C scores (good nutritional quality), while only 18.52% of the meat products received the same classification. Moreover, PBMAs employing the NPM from Brazil had a good nutritional profile (68.48%), in contrast to meat products, in which 80% predominantly had a poor nutritional profile. In addition, for the PAHO nutrient profile model (Brazil, Ministry of Health, National Health Surveillance Agency, 2022), both groups showed poor nutritional quality, with 87.1% and 92.3% for PBMAs and meat products, respectively. According to the NOVA criteria, almost 92% of the meat products were ultra-processed products, whereas a lower percentage (73.35%) of PBMAs were considered ultra-processed. According to the PB NPM criteria, meat products had poor nutritional profiles (81.48%), and PBMAs were homogeneously distributed, although the majority had good nutritional profiles (79.66%).

Table 6 shows the agreement between each nutritional classification scheme measured by Cohen's κ coefficient for plant-based meat

Table 5
F requency of classification of plant-based analogues meat and meat products, according to each NCSs, grouped according to sales category, main protein source and fat source.

Category	Nutritional Classification Schemes (NCSs)																			
	Nutri-Score				**NOVA**				**Brazil NPM**				**PB NPM**				**PAHO NPM**			
	D + E		**A + B + C**		**UPF**		**Non-UPF**		**Poor NP**		**Good NP**		**Poor NP**		**Good NP**		**Poor NP**		**Good NP**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Plant-based meat analogues																				
Burger	30[a]	25.64	87[b]	74.36	80[c]	68.38	37[d]	31.62	34[e]	29.06	83[f]	70.94	30[g]	25.64	87[h]	74.36	100[i]	85.47	17[j]	14.53
Breaded	10[a]	21.28	37[b]	78.72	33[c]	70.21	14[d]	29.79	10[e]	21.28	37[f]	78.72	10[g]	21.28	37[h]	78.72	40[i]	85.11	7[j]	14.89
Kibbeh	0[a]	0.00	27[b]	100.00	13[c]	48.15	14[c]	51.85	3[e]	11.11	24[f]	88.89	0[g]	0.00	27[h]	100	25[i]	92.59	2[j]	7.41
Cured meat	17[a]	30.36	39[b]	69.64	51[c]	91.07	5[d]	8.93	28[e]	50.00	28[e]	50.00	17[g]	30.36	39[h]	69.64	53[i]	94.64	3[j]	5.36
Meatballs	3[a]	10.00	27[b]	90.00	21[c]	70.00	9[d]	3.00	8[e]	26.67	22[f]	73.33	3[g]	10.00	27[h]	90	25[i]	83.33	5[j]	16.67
Meat	11[a]	15.28	61[b]	84.72	58[c]	80.56	14[d]	19.44	27[e]	37.50	45[f]	62.50	11[g]	15.28	61[h]	84.72	61[i]	84.72	11[j]	15.28
Total	71[a]	20.34	278[b]	79.65	256[c]	73.35	94[d]	26.93	110[e]	31.52	239[f]	68.48	71[g]	20.34	278[h]	79.66	304[i]	87.10	45[j]	12.89
Main protein source																				
Soy	46[a]	25.27	136[b]	74.73	156[c]	85.71	26[d]	14.29	82[e]	45.05	100[f]	54.95	46[g]	25.27	136[h]	74.73	165[i]	90.66	17[j]	9.34
Pea	19[a]	33.33	38[b]	66.67	56[c]	98.25	1d	1.75	19[e]	33.33	38[f]	66.67	19[g]	33.33	38[h]	66.67	51[i]	89.47	6[j]	10.53
Other*	2[a]	2.99	65[b]	97.01	32[c]	47.76	35[c]	47.76	2[e]	2.99	65[f]	97.01	2[g]	2.99	65[h]	97.01	56[i]	83.58	11[j]	16.42
None	4[a]	9.30	39[b]	90.70	4[c]	9.30	39[d]	90.70	7[e]	16.28	38[f]	83.72	4[g]	9.3	39[h]	90.70	32[i]	74.42	11[j]	25.58
Main fat source																				
Unsaturated FA	32[a]	16.58	161[b]	83.42	151[c]	78.24	42[d]	21.76	61[e]	31.61	132[f]	68.39	32[g]	16.58	161[h]	83.43	178[i]	92.23	15[j]	7.77
Saturated FA	34[a]	41.98	47[b]	58.02	70[c]	86.42	11[d]	13.58	35[e]	43.21	46[e]	56.79	34[g]	41.98	47[h]	58.02	73[i]	90.12	8[j]	9.88
None	5[a]	6.67	70[b]	93.33	35[c]	46.67	40[d]	53.33	14[e]	18.67	61[f]	81.33	5[g]	6.67	70[h]	93.33	53[i]	70.67	22[j]	29.33
Meat products																				
Burger	12[a]	23.53	39[b]	76.47	41[c]	80.39	10[d]	19.61	41[e]	80.39	10[f]	19.61	39[g]	76.47	12[h]	23.53	39[i]	76.47	12[j]	23.53
Breaded	20[a]	51.28	19[a]	48.72	37[c]	9.87	2[d]	5.13	10[e]	25.64	29[f]	74.36	20[g]	51.28	19[g]	48.72	38[i]	97.44	1[j]	2.56
Kibbeh	4[a]	80.00	1[b]	20.00	5[c]	100.00	0[d]	0.00	5[e]	100.0	0[f]	0.00	5[g]	80.00	1[h]	20.00	5[i]	100.00	0[j]	0.00
Cured meat	188[a]	96.41	7[b]	3.59	188[c]	96.41	7[d]	3.59	191[e]	97.95	4[f]	2.05	188[g]	96.41	7[h]	3.59	191[i]	97.95	4[j]	2.05
Meatballs	4[a]	57.14	3[a]	42.86	6[c]	85.71	1[d]	14.29	3[e]	42.86	4[e]	57.14	4[g]	57.14	3[g]	42.86	6[i]	85.71	1[j]	14.29
Meat	31[a]	57.41	65[b]	42.86	45[c]	83.33	29[d]	16.67	31[e]	57.41	23[e]	42.59	31[g]	57.41	23[g]	42.59	45[i]	83.33	9[j]	16.67
Total	286[a]	81.48	65[b]	18.52	322[c]	91.74	29[d]	8.26	281[e]	80.06	70[f]	19.94	286[g]	81.48	65[h]	18.52	324[i]	92.30	27[j]	7.70

Different letters on the same line, indicate significant differences (chi-square, $p < 0.05$). UPF: Ultra-processed food; FA: Fatty acids.

Table 6
Agreement between each nutritional classification schemes measured by Cohen's κ coefficient (with a 95% Confidence Interval), of plant-based meat analogues and meat products.

Category (κ; CI (Min; Max))	Nutri-Score/NOVA	Nutri-Score/Brazil NPM	Nutri-Score/PB NPM	Nutri-Score/PAHO NPM	NOVA/Brazil NPM	NOVA/PB PNM	NOVA/PAHO NPM	Brazil NPM/PB NPM	Brazil NPM/PAHO NPM	PB PNM/PAHO NPM
Plant-based meat analogues										
Burger	0.25 (0.14; 0.35)	**0.83**** (0.71; 0.94)	**1.00**** (1.00;1.00)	0.11 (0.05; 0.17)	0.26 (0.14; 0.38)	0.24 (0.13; 0.35)	0.31 (0.33; 0.65)	**0.82**** (0.71; 0.94)	0.13 (0.06; 0.20)	0.11 (0.04; 0.17)
Breaded	0.14 (−0.02; 0.29)	0.37 (0.03; 070)	**1.00**** (1.00;1.00)	0.09 (0.01; 0.17)	0.14 (0.02; 029)	0.13 (−0.02; 0.29)	0.11 (−0.18; 0.40)	0.36 (0.03; 0.69)	0.09 (0.01; 0.17)	0.09 (0.00; 0.17)
Kibbeh	0.00 (–;–)	0.00 (–;–)	0.00 (–;–)	0.00 (–;–)	0.09 (−0.18; 0.35)	−0.00 (−0.00; −0.00)	0.14 (−0.06; 0.34)	0.00 (0.00; 0.00)	0.02 (−0.02; 0.06)	0.00 (0.00; 0.00)
Cured meat	−0.03 (−0.14; 0.09)	**0.61*** (0.41; 0.71)	**1.00**** (1.00; 1.00)	0.05 (−0.01; 0.10)	−0.03 (−0.19; 0.12)	−0.02 (−0.14; 0.08)	0.46 (0.01; 0.92)	**0.61**[a] (0.40; 0.80)	0.11 (0.01; 0.23)	0.04 (−0.01; 0.10)
Meatballs	−0.01 (−0.17; 0.15)	0.04 (0.30; 0.39)	**1.00**** (1.00; 1.00)	0.04 (−0.02; 0.11)	0.27 (0.05; 049)	−0.01 (−0.17; 0.15)	0.09 (−0.28; 0.47)	0.04 (−0.29; 0.38)	0.14 (−0.01; 0.28)	0.04 (−0.02; 0.10)
Meat	0.08 (0.02; 0.15)	0.46 (0.26; 0.66)	**1.00**** (1.00; 1.00)	0.06 (0.01; 0.11)	0.11 (−0.04; 026)	0.08 (0.02; 0.14)	0.47 (0.20; 0.74)	0.46 (0.26; 0.66)	0.15 (0.02; 0.27)	0.06 (0.01; 0.11)
Total	0.13 (0.08; 0.17)	0.58 (0.49; 0.68)	**1.00**** (1.00; 1.00)	0.07 (0.04; 0.10)	0.19 (0.12; 0.26)	0.13 (0.08; 0.33)	0.28 (0.17; 0.39)	0.58 (0.49; 0.68)	0.11 (0.08; 0.16)	0.07 (0.05; 0.10)
Main protein source										
Soy	0.06 (0.00; 0.11)	0.47 (0.35; 059)	**1.00**** (1.00; 1.00)	0.07 (−0.01; 0.15)	0.14 (0.06; 0.22)	0.05 (0.00; 0.11)	0.29 (0.09; 049)	0.46 (0.34; 0.58)	0.16 (0.08; 0.22)	0.06 (0.03; 0.10)
Pea	−0.04 (0.11; 0.04)	**0.68**[a] (0.48; 0.89)	**1.00**** (1.00; 1.00)	0.11 (0.02; 0.21)	−0.04 (−0.11; 0.04)	−0.03 (−0.10; 0.03)	−0.03 (−0.09; 0.02)	**0.68**[a] (0.47; 0.89)	0.11 (0.01; 021)	0.11 (0.01; 0.20)
Other	0.07 (−0.03; 0.16)	**1.00**** (1.00; 1.00)	**1.00**** (1.00; 1.00)	0.01 (0.02; 0.21)	0.07 (−0.03; 016)	0.06 (−0.02; 0.15)	0.25 (0.08; 0.41)	**1.00**** (1.00; 1.00)	0.01 (−0.01; 0.03)	0.01 (−0.00; 0.03)
None	0.27 (−0.04; 0.59)	**0.69**[a] (0.36; 1.00)	**1.00**** (1.00; 1.00)	0.07 (−0.01; 0.15)	0.14 (−0.18; 0.46)	0.27 (−0.03; 0.58)	0.16 (−0.02; 0.33)	**0.69**[a] (0.35; 1.00)	0.06 (−0.08; 0.19)	0.00 (–;–)
Main fat source										
Unsaturated FA	0.06 (0.01; 0.15)	0.57 (0.45; 0.70)	**1.00**** (1.00; 1.00)	0.22 (0.17:0.7)	0.14 (0.06; 0.22)	0.05 (0.00; 0.11)	0.31 (0.15; 0.47)	0.57 (0.44; 0.70)	0.08 (0.04; 0.12)	0.03 (0.01; 0.05)
Saturated FA	0.20 (0.08; 0.32)	**0.62**[a] (0.45; 0.80)	**1.00**** (1.00; 1.00)	0.17 (0.12; 0.23)	0.21 (0.09; 0.34)	0.20 (0.08; 0.32)	0.23 (−0.07; 0.53)	0.62[a] (0.44; 0.79)	0.15 (0.05; 0.26)	0.14 (0.04; 0.24)
None	0.04 (−0.09; 0.16)	0.36 (0.07; 0.64)	**1.00**** (1.00; 1.00)	0.39 (0.28; 0.51)	0.14 (−0.05; 0.33)	0.03 (0.08; 0.32)	0.12 (−0.08; 0.32)	0.35 (0.07; 0.64)	0.13 (0.02; 0.24)	0.05 (0.00; 0.11)
Meat products										
Burger	0.07 (−0.22; 0.37)	0.53 (0.24; 0.82)	**1.00**** (1.00; 1.00)	0.23 (−0.07; 0.54)	0.00 (−0.28; 0.29)	0.07 (−0.22; 0.37)	**0.76**[a] (0.54; 0.99)	0.53 (0.24; 0.82)	−0.04 (−0.31; 0.22)	0.23 (−0.07; 0.54)
Breaded	0.10 (−0.04; 0.25)	0.39 (0.13; 0.65)	**1.00**** (1.00; 1.00)	0.05 (−0.05; 0.16)	−0.03 (−0.14; 0.07)	0.10 (0.04; 0.25)	−0.03 (−0.08; 0.00)	0.39 (0.13; 0.65)	0.01 (−0.02; 0.05)	0.05 (−0.05; 0.16)
Kibbeh	0.00 (–;–)	0.00 (–;–)	**1.00**** (1.00; 1.00)	0.00 (–;–)	0.00 (–;–)	0.00 (–;–)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00 (–;–)	0.00 (–;–)
Cured meat	0.11 (−0.14; 0.36)	0.53 (0.17; 0.89)	**1.00**** (1.00; 1.00)	0.53 (0.17; 0.89)	0.15 (−0.15; 0.47)	0.11 (−0.14; 0.36)	0.15 (−0.15; 0.47)	0.53 (0.17; 0.89)	**0.74**[a] (0.40; 1.00)	0.53 (0.17; 0.89)
Meatballs	0.36 (−0.41; 1.00)	**0.72**[a] (0.06; 1.00)	**1.00**** (1.00; 1.00)	0.36 (−0.41; 1.00)	0.22 (−0.34; 0.78)	0.36 (−0.41; 1.00)	**1.00**** (1.00; 1.00)	**0.72**[a] (0.06; 1.00)	0.22 (−0.34; 0.78)	0.36 (−0.41; 1.00)

(continued on next page)

Table 6 (*continued*)

Category	Nutri-Score/ NOVA	Nutri-Score/ Brazil NPM	Nutri-Score/ PB NPM	Nutri-Score/ PAHO NPM	NOVA/ Brazil NPM	NOVA/PB PNM	NOVA/ PAHO NPM	Brazil NPM/PB NPM	Brazil NPM/ PAHO NPM	PB PNM/ PAHO NPM
	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)	κ CI (Min; Max)
Meat	0.26 (0.03; 0.49)	**0.77**[a] (0.59; 0.94)	**1.00**** (1.00; 1.00)	0.34 (0.11; 0.56)	0.17 (−0.05; 0.40)	0.26 (0.03; 0.49)	**0.86**** (0.68; 1.00)	**0.77**[a] (0.59; 0.94)	0.26 (0.03; 0.49)	0.34 (0.11; 0.56)
Total	0.21 (0.08; 0.33)	**0.70**[a] (0.49; 0.68)	**1.00**** (1.00; 1.00)	0.32 (0.19; 0.45)	0.12 (0.01; 0.23)	0.21 (0.08; 0.33)	**0.65**[a] (0.50; 0.80)	**0.70**[a] (0.49; 0.68)	0.20 (0.08; 0.32)	0.32 (0.19; 0.45)

Nutritional Classification Schemes (NCS)

[a] Substantial agreement; ** excellent agreement; EV: energy value; FA; Fatty Acids; PB NPM: Plant-Based Nutrient Profile Model; PAHO NPM: Nutrient Profile of the Pan American Health Organization.

analogues and meat products. The agreement between different NCSs was generally slight or fair for PBMAs; on the other hand, excellent agreement was observed between the Nutri-Score and PB NPM. Substantial and excellent agreement was detected between the Nutri-Score and Brazil NPM and Brazil NPM and PB NPM, respectively, according to the sales categories (burger and cured meat), main source of protein (except for soy) and main source of fats (for saturated fatty acids). In meat products, substantial agreement was observed between NOVA and PAHO NPM for burgers, meatballs and meat; between Brazil NPM and PBNPM for meatballs and meat; and between Nutri-Score and Brazil NPM for meatballs and meat.

The disagreement between the NOVA classification and all other NCSs applied to assess the nutritional quality of PBMAs is notable, especially compared with the NPMs adopted for front-of-package nutrition labeling, such as the Nutri-Score and Brazil NPM. The Cohen's κ coefficients calculated for agreement between NOVA and the PAHO NPM for PBMAs and meat products were 0.28 and 0.65, respectively. The nutritional quality criterion adopted for the PAHO NPM is the strictest among all the NCSs used in this study and is therefore capable of identifying several critical nutrients at high levels. The agreement between NOVA and PAHO NPM in poor nutritional foods is substantial (Dickie et al., 2022) especially in identifying unhealthy foods. In contrast, in this study, the use of the NOVA classification proved to be incongruous in establishing the nutritional quality of plant-based meat analogues sold in Brazil. For example, the use of soy and pea isolated or concentrated protein was frequently identified in PBMAs classified as ultra-processed, but these products were considered to have good nutritional quality according to other NCSs. On the other hand, PBMAs without protein sources declared on labels were classified as non-ultra-processed foods and were composed of spinach, carrot, and broccoli. In summary, the NOVA classification cannot differentiate PBMAs with desirable nutritional characteristics, such as high protein and low saturated fat content, from those poor in protein.

In addition, the recommendation for decreasing the intake of processed foods that contain added sugars, salt and saturated fat due to their purported linkage with poor health outcomes does not apply to most PBMAs evaluated in this study. Therefore, processed food is not unhealthy by definition (Fitzgerald, 2023) and the use of additives such as thickeners (45.8%) and flavorings (39.8%) for industrial processing of vegetal proteins was decisive for the classification of PBMAs as ultra-processed foods and not the critical nutrient profile. The frequency of use of the additives in PBMAs is presented in Table 2S.

In terms of the Nutri-Score, Brazil NPM and PB NPM appear to be the most suitable for differentiating nutritionally poor PBMAs from good-quality PBMAs. The agreement between the PB PNM and Nutri-Score was excellent, probably due to the use of the Nutri-Score NPM as the basis for constructing the PB NPM; however, the NOVA classification criteria were also used to construct the PB NPM, and slight agreement (κ = 0.13) was observed between these last two NCSs for total PBMAs. In this context, the Brazil NPM appears to be the best NCS for evaluating the nutritional quality of PBMAs, given its agreement with the Nutri-Score for burger (κ = 0.83) and cured meat (κ = 0.61). The Nutri-Score has been employed for nutritional quality evaluation for PBMAs in several studies (Bryngelsson et al., 2022; Cutroneo et al., 2022; de las Heras-Delgado et al., 2023; Huybers and Roodenburg, 2024; Rodríguez-Martín et al., 2023). A total of 96.2% of the plant-based burgers and 67.5% of the plant-based cured meats were classified as Nutri-Score (A + B + C), while 45.6% of the meat burgers and 69.2% of the cured meats were classified as D + E in the Food Labeling of Italian Products Project (Cutroneo et al., 2022). In a similar Swedish plant-based meat analog study, the Nutri-Score (A + B + C) was 89% (n = 96), and the E score was not assigned to any product (Bryngelsson et al., 2022). Two studies carried out in Spain classified the majority (55%–90.3%) of PBMAs with Nutri-Scores (A + B + C); however, between 41% and 61% of PBMAs were classified as ultra-processed food according to the NOVA classification (de las Heras-Delgado et al., 2023; Rodríguez-Martín et al., 2023).

Although the NCSs used in this study are important for evaluating the nutritional quality of PBMAs, they do not cover all the important nutritional aspects when aiming to replace meat products, which should involve a multifaceted approach, including macronutrient analysis, sensory evaluation and, digestibility studies. Furthermore, the presence of positive nutrients, such as vitamins B, iron, zinc, and soluble and insoluble fibers, and good protein quality must be considered as differentials in nutritionally adequate PBMAs.

The use of nutritional claims in PBMAs labels was not frequent, especially for claims for high content (6%) and a source of fibers (14%) (Table 7). The high fiber content in plant-based food is one of the main factors associated with the beneficial health effects observed in consumers on vegan diets (Clarys et al., 2014; Tomova et al., 2019). The food industry developed PBMAs that have physical (texture and water-holding capacity) and sensorial (color and taste) characteristics similar to those of meat products, which are low in fibers (burger median: 0.5 g/100 g; cured meat median: 0.0 g/100 g). The use of nutritional claims for the source of fibers could be employed by 68.5% of the PBMAs, especially for burgers and meatballs, reaching 84.6% and 80.0% of the total products, respectively.

Similarly, only 8.5% and 12.8% of plant-based burgers use nutritional claims because of their high content and source of protein, respectively. A recent Brazilian legislation update (Brazil, Ministry of Health, & National Health Surveillance Agency, 2020a; Brazil, Ministry of Health, National Health Surveillance Agency, 2020b) included the requirement of a specific indispensable amino acid profile for the use of protein nutritional claims (histidine: 15 mg/g of protein; isoleucine: 30 mg/g; leucine: 59 mg/g; lysine: 45 mg/g; methionine plus cysteine: 22 mg/g; phenylalanine plus tyrosine: 38 mg/g; threonine: 23 mg/g;

Table 7
Frequency of use of nutrition claims in plant-based meat analogues labels.

		Nutritional Claims							
		Proteins		Fibers		Iron		Vitamin B12	
		Source	**High content**	**Source**	**High content**	**Source**	**High content**	**Source**	**High content**
Category	**N**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
Burger	117	15 (12.8)	10 (8.5)	18 (15.4)	8 (6.8)	15 (12.8)	5 (4.27)	13 (11.1)	7 (6.0)
Breaded	47	2 (4.3)	2(4.3)	4 (8.5)	8 (17.0)	9 (19.1)	3 (6.8)	9 (19.1)	5 (10.6)
Kibbeh	27	4 (14.8)	1 (3.7)	6 (22.2)	2 (7,4)	5 (18.5)	1 (3.7)	4 (14.8,0)	1 (3.7)
Cured meat	56	4 (7.1)	10 (17.9)	7 (12,5)	0 (0.0)	6 (10.7)	2 (3.6)	5 (8.9)	1 (1.7)
Meatballs	30	2 (6.7)	3 (10.0)	7 (23.3)	1 (3.3)	7 (23.3)	1 (3.3)	5 (16.6)	1 (3.3)
Meat	72	6 (8.3)	8 (11.1)	10 (13.9)	2 (2.8)	19 (26.4)	3 (42)	23 (31.9)	8 (11.1)
Total	**349**	**33 (9.5)**	**34 (9.7)**	**52 (14.3)**	**21 (6.0)**	**61 (17.5)**	**15 (4.3)**	**59 (16.9)**	**23 (6.6)**

tryptophan: 6 mg/g; valine: 39 mg/g). In general, legumes such as soy, peas, chickpeas, beans and cereals such as wheat and quinoa, which are usually employed as protein sources in meat analogues in Brazil, have different digestible indispensable amino acid scores (DIAASs). Potato and soy proteins are classified as high-quality proteins with average DIASS values equivalent to 100 and 91, respectively (Herreman et al., 2020). Furthermore, an interesting strategy for PBMA development is that soy and potato proteins can complement a broad range of plant proteins to compensate for the indispensable limitations of amino acids. The combination of rice/bean protein (2:1) has the potential to achieve optimal nutritional efficiency when combined with plant proteins alone or when supplemented with methionine or cysteine plus lysine.

Lysine deficiency was detected in plant-based burgers marketed in Italy; however, the same phenomenon was observed in meat-based burgers. However, the sum of essential amino acids from plant-based burgers was within the range of sufficiency, and vegetable proteins showed good digestibility (from 40% to 55%) compared to that of meat-based burgers (from 53% to 69%) (Cutroneo et al., 2023).

Iron and vitamin B_{12} were present in 20.5% and 12.8%, respectively, of the plant-based burgers. For all PBMAs analyzed, nutritional claims for iron and B_{12} were observed in 22.9% and 17.5%, respectively. These results indicate the infrequent use of iron and vitamin B_{12} fortification in PBMAs marketed in Brazil. A recently published meta-analysis concluded that children and adolescents on plant-based diets had significantly lower vitamin B_{12} levels than did those on omnivorous diets (Jensen, 2023). In general, vitamin B_{12} intake among vegans was lower (0.24–0.49 mg) than the recommended intake (2.4 mg). On the other hand, vegan diets were not correlated with iron or vitamins B_1 or B_6 lower levels intake (Bakaloudi et al., 2021).

4. Conclusion

Currently, consumers are increasingly inclined toward plant-based meat analogues when adopting flexitarian and vegan diets. The main drivers of this market are healthiness, ethics in husbandry and environmental sustainability. The first generation of plant-based products, which were typically developed using methods similar to those employed in the meat industry, is being replaced by new offerings. The launch of new PBMAs and several reformulations offer market that is wide and vast for demanding consumers. This study showed that PBMAs supplied to the Brazilian market are diverse both in terms of vegetal protein sources and nutrient quality. Among several types of meat analogues, 117 were classified as burgers, and 182 products employed soy as the main protein ingredient. The nutritional composition of PBMAs was heterogeneous, even within the same sales category, and according to PCA, total fat, saturated fat and energy content explained the most variance (0.3286). The use of different NCSs is strategic for PBMAs' nutritional quality evaluation, and the principal Nutri-Score was able to effectively differentiate products with poor nutritional quality. In this way, the employment of NPM from Brazil is recommended as a driver for PBMA choices, especially due to the excellent agreement between the Nutri-Score and NPM from Brazil for burgers. In addition, the identification profile of PBMAs must include the requirement for an amount of vegetal protein equivalent to and the use of B vitamins (B_2, B_3 and B_{12}) and iron.

CRediT authorship contribution statement

Nathalia Tarossi Locatelli: Investigation, Methodology, Data curation, Formal analysis, Writing – original draft. **Grace Fen Ning Chen:** Investigation, Methodology, Data curation, Formal analysis. **Mariana Frazão Batista:** Investigation, Methodology, Data curation, Formal analysis. **Júnior Mendes Furlan:** Investigation, Methodology, Data curation, Formal analysis, Writing – review & editing. **Roger Wagner:** Investigation, Methodology, Data curation, Formal analysis, Writing – review & editing. **Daniel Henrique Bandoni:** Conceptualization, Funding acquisition, Project administration, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Veridiana Vera de Rosso:** Conceptualization, Funding acquisition, Project administration, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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.

Data availability

The data that has been used is confidential.

Acknowledgments

This work was supported by The Good Food Institute Brazil (GFI Brazil).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crfs.2024.100796.

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