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Comparative assessment of the nutritional composition and degree of processing of meat products and their plant-based analogues

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ABSTRACT

A cross-sectional study was conducted to compare the nutritional composition and the degree of processing of prepackaged plant-based meat analogues (PBMA) products (n=63) and their meat counterparts (n=153). Labeling data was collected from all the products available for sale in a main retail chain in Portugal. The products were categorized into burgers, meatballs, sausages, smoked sausages, breaded products, and others. Foods were classified by degree of processing using NOVA. Differences in the nutritional composition (energy, total and saturated fat, carbohydrates, sugars, protein, fiber, and salt) overall and across categories were assessed. Compared to meat-based products (MBP), PBMA had a higher median/100 g carbohydrate (9.8 g *vs.* 3.0 g, p<0.001), sugar (1.6 g *vs.*0.6 g, p<0.001) and fiber (3.7 g *vs.*0.6 g, p<0.001) but lower energy (203 kcal *vs.*220 kcal, p=0.026), fat (9.6 g *vs.*14.0 g, p<0.001), saturated fat (1.0 g *vs.*5.4 g, p<0.001) and salt (1.4 g *vs.*1.7 g, p=0.007). A higher proportion of ultra-processed foods was found among PBMA products (100 % *vs.* 85.6 %). All PBMA were ultra-processed but with higher fiber content, and lower fat, saturated fat, and salt levels, despite category variations. The differences in nutritional composition underscore that PBMA and MBP should not be considered equivalent alternatives.

1. Introduction

The current global food system is widely recognized as unsustainable due to its significant contribution to greenhouse gas emissions, land conversion, deforestation, and biodiversity loss (Musicus et al., 2022; World Health Organization, 2019). Moreover, there is a growing concern over the global shift towards unhealthy dietary habits, which is characterized by excessive consumption of heavily processed and animal-based foods, particularly red meat (Musicus et al., 2022). These consumption patterns have been strongly correlated with the alarming rise in obesity, type 2 diabetes, and other noncommunicable diseases (NCDs) (Musicus et al., 2022; World Health Organization, 2019; Zacher, 2021).

Plant-based diet has gaining popularity due to positive health concerns, environmental sustainability, and animal welfare (Clark et al., 2022; Lantern, 2021; Mascaraque, 2020; World Health Organization, 2019). Recognizing the importance of promoting both healthy and sustainable diets, international organizations such as the World Health Organization (WHO) and EAT Lancet have emphasized the need for a shift towards plant-based foods and a reduction in animal-based foods (Willett et al., 2019; World Health Organization, 2019).

Traditionally plant-based diets are centered on unprocessed or minimally processed food such as fruit, vegetables, pulses, nuts and wholegrains (Ostfeld, 2017). However, “modern” plant-based diets may include a significant use of products that fall into the ultra-processed foods (UPFs) category, for example, the plant-based meat analogues (PBMA) (Macdiarmid, 2022; World Health Organization, 2021), which are specifically designed to mimic the sensory characteristics (taste, texture, appearance) and nutritional aspects of meat (Kyriakopoulou et al., 2021). Consequently, ingredient selection is focused on achieving these objectives (Ahmad et al., 2022; Fiorentini et al., 2020). Some primary examples of plant materials utilized in the development of meat alternatives feature plant-based protein sources such as soybean, gluten, and wheat protein in both textured and non-textured forms (Asgar et al., 2010; Kyriakopoulou et al., 2021). Moreover, these analogues contain significant amounts of water, flavorings, oils or fats, binding agents, and

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coloring agents (Kyriakopoulou et al., 2021).

According to NOVA classification system (Monteiro et al., 2019), UPFs are formulations of substances derived from whole foods, such as starches, sugars, fats and protein isolates, with little, if any, whole food, and often with added flavors, colors, emulsifiers and other cosmetic additives to improve shelf-life, palatability and visual appearance (Monteiro et al., 2019). UPFs are frequently energy-dense products, high in added sugar, unhealthy fats, salt, and low in dietary fiber, protein, vitamins, and minerals (Zhang et al., 2021).

As a response to the growing demand for plant-based alternatives, the PBMA market is expanding rapidly, with plant-based burgers and sausages driving category growth (Smart Protein Project, 2021). The global plant-based meat market was valued at $5.3 billion in 2021 and is projected to reach $33.3 billion by 2031 (Supriya B and Vitika, 2022).

Considering the lack of knowledge that still exists regarding nutritional value of PBMA and the "health halo" associated with them (Macdiarmid, 2022), WHO Europe has issued recommendations regarding these products, emphasizing the need to compare meat and dairy substitutes with their animal-source counterparts when analyzing nutritional content (Wickramasinghe et al., 2021).

Recent studies have significantly contributed to advancing our understanding of PBMA nutritional profiles. A nutritional assessment of PBMA in Spanish supermarkets (Rizzolo-Brime et al., 2023) observed that while these products exhibit variable nutritional compositions within and between categories, the majority meet the criteria of ultra-processed foods. Of particular concern highlighted by most studies is the typically elevated salt content found in these products (Alessandrini et al., 2021; Bryngelsson et al., 2022; Curtain and Grafenauer, 2019; Cutroneo et al., 2022; de Las Heras-Delgado et al., 2023; Romão et al., 2022), despite many PBMA having a better nutrient profile than their meat counterparts (de Las Heras-Delgado et al., 2023). This underscores the critical need for comprehensive nutritional and quality information about PBMAs to effectively formulate guidelines upon which robust and effective policies can be developed to guide both the industry and consumers (Rizzolo-Brime et al., 2023; Wickramasinghe et al., 2021)

In line with these recommendations and recent research, the aim of this study was to compare the nutritional composition, and the degree of processing between PBMA and their meat counterparts at a major retail chain in Portugal.

2. Materials and methods

2.1. Eligible food products and categories description

Labeling data of prepackaged PBMA products and their meat counterparts available for sale were assessed through a cross-sectional study in one of the main retail chains in Portugal. Plant-based foods that mimic meat-based products were considered eligible. Items such as tofu, tempeh, seitan, and falafel, were excluded since they are not considered meat analogues. Furthermore, the assessment did not include seafood and fish products, either plant or animal based. For comparison, meat-based products (MBP) were chosen to correspond to the PBMA included.

The PBMAs collected were categorized into six categories (Table 1): burgers, meatballs, sausages, smoked sausages, breaded products, and others. The 'others' category consisted of products that did not fit into any of the other five predefined categories. For comparison, meat products were chosen to correspond to each of the six categories of PBMA. It's worth noting that only PBMA products fell into the 'others' category, there were no MB products in this category for comparison.

2.2. Data collection

Label information was collected in-store by photographs or online at the retailer website (from February to April 2023). Regulated data, defined by Council Regulation (EU) 1169/2011 (Parlamento Europeu e do Conselho) was collected for each product to obtain comprehensive nutritional information. This included the product's descriptive name, energy (kcal), total and saturated fat (g), carbohydrates (g), sugars (g), protein (g), fiber (g), and salt (g) content per 100 g, as well as the list of ingredients. In cases where a nutrient was considered negligible or labeled as "trace," a value of 0 was assigned. The collected data was organized and summarized using Microsoft Excel® software.

2.3. Degree of processing categorization

The degree of processing for each product was assessed using the NOVA classification system (Monteiro et al., 2019), which classifies foods into four groups: 1. Unprocessed or minimally processed foods, 2. Processed culinary ingredients, 3. Processed foods, and 4. Ultra-processed foods (Monteiro et al., 2019). Additionally, a detailed examination was conducted to identify the profile of ultra-processed MBPs and PBMAs. This assessment involved counting the number of ingredients that contributed to classify each food as ultra-processed and identifying the key ingredients responsible for this classification. These

Table 1
Description of plant-based meat analogues and meat-based products.

Food categories	Plant-based products	n	%	Meat-based products	n	%
Burgers	A plant-based product that contains "burger" and/or "pattie/patty" in the product name or is a meat-free product appearing to mimic meat burger	23	36.5	Beef, chicken, pork and turkey burgers	18	11.8
Meatballs	A plant-based product that contains "meatballs" in the product name or is a meat free product appearing to mimic meatballs	5	7.9	Beef, pork and chicken meatballs	7	4.6
Sausages	A plant-based product that contains "Wiener","Frankfurter", and/or "Hot Dog" in the product name or is a meat-free product appearing to mimic meat sausages	9	14.3	Poultry or pork fresh sausage (Viena; Bockwust; Kinderwurst; Crioulo; Toscana; Wurstel; Frankfurt; Bratwurst; Grill) And poultry or pork canned sausages (Frankfurt; Cocktail; Bockwust; Hot Dog; Wienerwurst)	61	39.9
Smoked sausages	Plant-based products appearing to mimic Portuguese traditional smoked sausages such as "Alheira","Morcela" and "Chouriço"	3	4.8	Portuguese traditional smoked sausages including "Alheira", "Chouriço", "Morcela" and "Linguiça"	44	28.8
Breaded Products	A plant-based product that contains "Nuggets", "Fingers", and/or "Schnitzels", and/or "Crispy tenders or slices" in the product name or any meat-free product designed to resemble meat, and coated with a layer of batter or breading	11	17.5	Chicken nuggets, Pork and beef rissoles, beef croquettes, chicken strips, fingers and wings, breaded chicken	23	15.0
Others	A plant-based product that contains "Pieces", "chunks",'"bites", "strips" in the product name or is a meat-free product appearing to mimic these meat products versions	12	19.0	N/A	N/A	N/A
Total		63	100		153	100

ingredients were named "UPFs ingredients".

2.4. Data analysis

Statistical analysis was performed using IBM SPSS Statistics, Version 29.0, with the significance level set at p<0.05. The Kolmogorov-Smirnov test was used to assess normality of data distribution. Since the nutritional data were not normally distributed, energy, macronutrient, fiber, and salt values were reported as median and interquartile ranges. Descriptive statistics (median, P25 and P75) of energy and selected nutrients (carbohydrates, sugars, fat, saturated fat, protein, dietary fiber, and salt) were calculated per 100 g. For products with less than 0.5 g of fiber or sugar (indicated on the label as <0.5), a value of 0.49 was assigned. To compare the nutritional values of PBMA and their MBP counterparts overall and across categories, the Mann-Whitney test for two independent samples was used. The effect size was calculated to evaluate the magnitude of the difference between the nutritional values of PBMA and MBP across categories that exhibited statistical significance. The proportion (%) of PBMA and MBP across the four NOVA categories was reported within each of the six food categories.

3. Results

Data from 63 PBMA products were identified. Among these, 36.5 % were classified as burgers, 7.9 % as meatballs, 14.3 % as sausages, 4.8 % as smoked sausages, 17.5 % as breaded products and 19 % fell into the 'others' category (Table 1).

Regarding MBP counterparts, 164 products were identified, from which 11 were excluded due to missing nutritional information, remaining 153 products for the assessment. Among these, 11.8 % were classified as burgers, 4.6 % as meatballs, 39.9 % as sausages, 28.8 % as smoked sausages, 15 % as breaded products and none MBP fell into the 'other' category (Table 1).

3.1. Nutritional composition characterization

Regarding energy content, overall, PBMA had lower median values compared to their MBP counterparts (203 kcal *vs.* 220 kcal, p=0.026). The assessment by category showed that PBMA, compared to their MBP, contained higher median energy content in burger products (185 kcal *vs.* 167 kcal, p=0.043, effect size 0.32) but lower in smoked sausages (152 kcal *vs.* 344 kcal, p<0.001, effect size –0.42). No significant differences were found between PBMA and MPB for the remaining categories (Table 2).

In terms of total fat content, PBMA generally had lower median values compared to their MBP counterparts (9.6 g *vs.* 14.0 g, p<0.001). Upon closer examination by category, PBMA, compared to their MBP, presented lower median fat content in smoked sausages (5.2 g *vs.* 30.5 g, p<0.001, effect size –0.42) category. No significant differences were found between PBMA and MPB for the remaining four categories (Table 2).

About saturated fat content, overall, PBMA presented lower median values compared to their MBP counterparts (1 g *vs.* 5.4 g, p<0.001). The assessment by category consistently showed that PBMA, compared to their MBP, contained lower median saturated fat content across all categories, with the most significant difference observed in meatballs (0.8 g *vs.* 5.3 g, p<0.001, effect size –0.82) and smoked sausages (0.8 g *vs.* 11.2 g, p<0.001, effect size –0.42) (Table 2).

Regarding carbohydrate content, PBMA generally exhibited higher median values than their MBP or MBP counterparts (9.8 g *vs.* 3 g, p<0.001). Compared to their MBP, PBMA had higher median carbohydrate content in the burgers category (11 g *vs.* 2.5 g, p<0.001, effect size 0.71) and meatballs (9.9 g *vs.* 3.1 g, p=0.048, effect size 0.56) category. No significant differences were found between PBMA and MPB for the remaining three categories (Table 2).

As for sugar content, PBMA mostly presented higher median values compared to their MBP counterparts (1.6 g *vs.* 0.6 g, p<0.001). The assessment by category revealed notably higher median sugar content in burgers PBMA category (2.2 g *vs.* 0.5 g, p<0.001, effect size 0.66), compared to their MBP, with no significant differences were found between PBMA and MPB for the remaining four categories (Table 2).

Moving on to protein content, overall, there were no significant differences between PBMA and their MBP counterparts (15 g *vs.* 14 g, p=0.895). However, upon categorical analysis, PBMA showed higher median protein content in the sausages category (15 g *vs.* 12.4 g, p=0.005, effect size 0.33), compared to their MBP. Nevertheless, no significant differences were found between PBMA and MPB for the remaining four categories (Table 2).

In terms of fiber content, PBMA generally presented higher median values compared to their MBP counterparts (3.7 g *vs.* 0.6 g, p<0.001). The assessment by category further elucidates these differences, with PBMA showing higher median fiber content in burgers (3.3 g *vs.* 0.5 g, p<0.001, effect size 0.80), sausages (0.49 g *vs.* 0.30 g, p=0.037, effect size 0.47), meatballs (3.4 g *vs.* 1.6 g, p=0.004, effect size 0.83), and breaded products (5.3 g *vs.* 1.4 g, p<0.001, effect size 0.76) categories, compared to their MBP. However, no significant differences were found between PBMA and MPB for the smoked sausages category (Table 2).

Regarding salt content, overall, PBMA exhibited lower median values compared to their MBP counterparts (1.4 g *vs.* 1.6 g, p=0.007). Upon categories assessment, PBMA compared to their MBP, presented higher median salt content in burgers (1.5 g *vs.* 0.7 g, p<0.001, effect size 0.57) and meatballs (1.4 g *vs.* 0.5 g, p=0.030, effect size 0.61) categories. Nonetheless, no significant differences were found between PBMA and MPB for the remaining categories (Table 2).

Table S1 shows in detail the minimum and maximum values of each nutritional parameter, according to the PBMA and MBP food categories. In addition, boxplots depicting the data distribution of the study's PBMA categories compared to their meat-based counterparts are shown in Figures S1-S8.

3.2. Degree of processing classification (NOVA)

Overall, PBMA exhibited a higher proportion of UPFs products compared to MBP (100 % and 85.6 %, p<0.001). The assessment by category showed that PBMA presented higher proportion of UPFs in burgers category in comparison with their meat counterparts (100 % *vs.* 55.6 %, p<0.001). No statistically significant differences were observed for the remaining categories (Table 3).

3.3. Ultra-processed ingredients profile

The number of ingredients that contributed to the classification as UPFs varied between 1 and 17 in PBMA and between 1 and 19 for MBP. Overall, there were no significant differences in the number of UPF ingredients between PBMA and their MBP counterparts. However, the assessment by category showed that PBMA contained higher median number of UPF ingredients in burgers (5 *vs.* 3, p=0.018) compared to their meat counterparts, but lower in the 'others' category (3 *vs.* 9.5, p=0.016). No significant differences were found for the remaining categories.

Within ultra-processed PBMA products (n=63), protein sources were the most prevalent UPFs ingredient (43 %), with predominance of soy protein (51 %). Thickeners and stabilizers were the following category (17 %), predominating methylcellulose (72 %). Flavor and food enhancers ranked third (16 %) among UPF ingredients, with aroma additives prevailing (88 %) (Table S2). Among ultra-processed MBP (n=131), emulsifiers, thickeners, and stabilizers were the most frequently utilized (33 %), prevailing phosphates (48 %). Flavor and food enhancers were the following category (20 %) with the predominance of aroma additives (65 %). Sources of protein ranked third (19 %) among UPF ingredients, prevailing the soy protein (48 %) (Table S3).

Table 2
Energy and nutrient content of plant-based meat analogues (n=63) and their meat equivalents (n=153) expressed in median and percentiles P25 and P75) per 100 g.

	Energy (Kcal) P50 (P25-P75)	**p-value**	**Fat (g)** P50 (P25-P75)	**p-value**	**Saturated fat (g)** P50 (P25-P75)	**p-value**	**Carbohydrates (g)** P50 (P25-P75)	**p-value**	**Sugars (g)** P50 (P25-P75)	**p-value**	**Protein (g)** P50 (P25-P75)	**p-value**	**Fiber (g)** P50 (P25-P75)	**p-value**	**Salt (g)** P50 (P25-P75)	**p-value**
Total																
Plant-Based (n=63)	203 (173−226)	0.026	9.6 (7.2–14.0)	<0.001	1 (0.8–1.4)	<0.001	9.8 (3.5–17.6)	<0.001	1.6 (0.6–2.6)	<0.001	15 (11−19)	0.895	3.7 (2.3–6)	<0.001	1.4 (1–1.7)	0.007
Animal-based (n=153)	220 (173−276)		14.0 (10.0–22.5)		5.4 (3–9.1)		3.0 (1.0–9.0)		0.6 (0.5–1.1)		14 (12–18)		0.6 (0.49–1.6)		1.7 (1.1–2.2)	
Burgers																
Plant-Based (n=23)	185 (179−226)	0.043	8.9 (7.7–12.0)	0.684	1.0 (0.9–1.2)	<0.001	11.0 (5.1–15.0)	<0.001	2.2 (1.6–3.1)	<0.001	17.0 (13.0–20.0)	0.452	3.3 (2.3–6.0)	<0.001	1.5 (1.1–1.8)	<0.001
Animal-based (n=18)	167 (137−219)		8.2 (5.5–15.7)		3.2 (2.3–7.1)		2.5 (1.1–3.2)		0.5 (0.49–1.0)		17.1 (16.7–19.0)		0.5 (0.49–0.5)		0.7 (0.3–1.1)	
Sausages																
Plant-Based (n=9)	224 (195−225)	0.079	18.0 (14.0–18.0)	0.276	2.4 (1.6–2.4)	<0.001	0.6 (0.6–4.0)	0.404	0.49 (0.49–0.59)	0.077	15.0 (13.5–15.0)	0.005	0.49 (0.49–5.1)	0.037	2.0 (1.5–2.0)	0.915
Animal-based (n=61)	184 (148−226)		14.0 (9.5–19.2)		5.4 (3.6–7.4)		1.8 (0.8–3.5)		0.5 (0.5–0.75)		12.4 (11.0–13.7)		0.3 (0.0–0.5)		1.8 (1.6–2.0)	
Meatballs																
Plant-Based (n=5)	175 (156−218)	0.943	7.3 (5.8–11.3)	0.149	0.8 (0.7–1.1)	0.003	9.9 (5.6–13.7)	0.048	1.0 (0.7–2.9)	0.343	17.0 (11.7–19.8)	0.639	3.4 (2.4–4.8)	0.004	1.4 (1.1–1.6)	0.030
Animal-based (n=8)	199 (146−229)		11.5 (6.8–17.0)		5.3 (2.8–7.3)		3.1 (2.1–4.6)		0.8 (0.5–1.4)		14.5 (5.7–17.4)		1.6 (0.5–3.8)		0.5 (0.2–0.9)	
Smoked sausages																
Plant-Based (n=3)	152 (147-.)	<0.001	5.2 (4.9-.)	<0.001	0.8 (0.8-.)	<0.001	7.6 (1.9-.)	0.500	1.9 (1.1-.)	0.063	25.0 (7.1-.)	0.605	2.3 (2.2-.)	0.103	1.4 (1.2-.)	0.262
Animal-based (n=44)	344 (235−426)		30.5 (15.3–36.6)		11.2 (5.8–15.0)		3.0 (1.7–12.2)		0.8 (0.5–1.7)		19.5 (14.0–22.9)		1.6 (0.3–1.7)		2.7 (1.7–3.5)	
Breaded Products																
Plant-Based (n=11)	229 (203−250)	0.258	10.2 (7.8–11.7)	0.188	0.9 (0.8–1.4)	<0.001	19.0 (17.0–23.0)	0.243	1.4 (0.7–2.1)	0.772	13.1 (9.0–15.0)	0.772	5.3 (4.0–5.7)	<0.001	1.0 (1.0–1.3)	0.537
Animal-based (n=23)	254 (208−266)		14.0 (9.6–14.0)		2.0 (1.5–2.8)		23.0 (19.0–25.0)		1.6 (0.7–3.6)		13.0 (9.8–14.0)		1.4 (1.1–2.2)		1.0 (0.9–1.2)	
Others																
Plant-Based (n=12)	178 (133−223)	N/A	10.0 (3.0–13.0)	N/A	1.0 (0.5–1.6)	N/A	6.5 (2.0–20.0)	N/A	1.2 (0.2–20.2)	N/A	10.2 (5.0–18.6)	N/A	6.3 (3.7–7.2)	N/A	1.1 (0.9–1.6)	N/A
Animal-based (n=0)	N/A		N/A		N/A		N/A		N/A		N/A		N/A		N/A	

Table 3
Degree of processing (NOVA) of plant-based meat analogues and meat-based products.

	Ultra-Processed (%)		Processed (%)		Unprocessed/ minimally processed (%)	
Categories	PBMA	MBP	PBMA	MBP	PBMA	MBP
Burgers	100	55.6	0	27.8	0	16.7
Sausages		100		0		0
Meatballs		71.4		28.6		0
Smoked Sausages		75.0		25.0		0
Breaded Products		95.7		4.3		0
Others		N/A		N/A		N/A

MBP, meat-based products; PBMA, plant-based meat analogues; N/A, not available

4. Discussion

In general, PBMA products exhibited a higher content of fiber, carbohydrate, and sugar but lower levels of energy, total fat, saturated fat, and salt in comparison with their MBP counterparts. Some of these nutritional characteristics, particularly the high fiber and low saturated fat and salt content play a crucial role in NCDs risk, being considered the leading dietary factors that contribute to the global burden of disease (Bruins et al., 2019). From this perspective, PBMA as a whole showed the most favorable nutritional profile although heterogeneous results were observed across categories.

These findings are consistent with other studies, conducted in different countries, which also described a beneficial nutritional profile for PBMA products (Alessandrini et al., 2021; Cole et al., 2022; Cutroneo et al., 2022; Romão et al., 2022). In contrast, one common drawback observed in other studies, is the relatively high salt/sodium content of PBMA products compared to their meat counterparts (Alessandrini et al., 2021; Cole et al., 2022; Cutroneo et al., 2022; Romão et al., 2022). In the present study, and in line with other studies results (Costa-Catala et al., 2023; Gréa et al., 2023), PBMA generally showed lower salt content than their MBP counterparts, although there were variations within categories. In plant-based food products, salt is mainly used as flavor enhancer to better improve the sensorial consumption experience, rather than acting as a preservative as observed in meat products due to their inherently lower microbiological stability (Costa-Catala et al., 2023). Additionally, the incorporation of herbs and spices in the development of plant-based products aids in reducing salt content without compromising sensory appeal (Dougkas et al., 2019).

Notably, PBMA burgers and meatballs, exhibited higher salt content than their meat-based counterparts. Plant-based burgers are popular meat analogues categories in the market, representing the largest category in this assessment (36.5 % of all PBMA samples), and besides their higher salt content, they were more energetically dense, and sugary while also having lower saturated fat and higher fiber content than their MBP counterparts.

The issue of excess salt in Portugal is of great importance given that the average daily intake of salt per capita is 10.7 g (Lopes et al., 2017), more than the double recommended by the WHO (<5 g/day) (World Health Organization, 2012). Excessive salt consumption is associated with cardiovascular disease, which is the leading cause of death both globally and nationally (European Observatory on Health Systems and Policies, 2021; World Health Organization, 2012). This underscores the importance of reformulating industrial food including plant-based alternatives as well extend existing Portuguese public health policies on salt reduction/taxation in food products to this type of products. In Portugal, traditional sausages hold significant popularity and are esteemed as smoked delicacies characterized by high salt content. In fact, processed meats, including smoked sausages, significantly contribute to salt intake in Portugal (Lopes et al., 2017). In our study, PBMA smoked sausages, which aim to mimic traditional Portuguese smoked sausages such as “Alheira", "Chouriço", "Morcela" and "Linguiça”, had lower energy, total fat, with the saturated fat and nearly half the salt content of their meat counterparts. However, the observed differences between PBMA and MBP smoked sausages, particularly in salt content, can be attributed to the extensive range of products within the conventional smoked sausage category. This could have a significant overall influence on the results, making PBMA lower in salt.

Regarding PBMA sausages, they were lower in saturated fat and higher in fiber and protein content compared to their meat counterparts, showing a more favorable nutrient profile. In our study, despite category differences, plant-based sausages were the category with higher statistically levels of protein that heir meat-based equivalent, in line with (Gréa et al., 2023) and (Katidi et al., 2023). This seems to be explained by the legumes and cereals used to make plant-based sausages, notably boosting the protein content compared to meat-based ones (Costa-Catala et al., 2023). However, although salt content did not differ significantly between the two, it should be noted that both products still contained high amounts of salt.

Another notable difference between the results from this study and others concerns the protein content that was similar in the PBMA and their meat counterparts whereas in most studies (Alessandrini et al., 2021; Cole et al., 2022; Cutroneo et al., 2022; Romão et al., 2022), PBMA products contained less protein than their MPB counterparts. Our findings are in line with other recent studies on PBMA (Costa-Catala et al., 2023), which seems to be a change largely attributed to the current exploration of plant-based protein blends, aimed to overcome the protein gap between plant-based and animal-based meats (Gorissen et al., 2018). Notably, the incorporation of legumes into PBMA formulations has emerged as a significant contributor to elevated protein levels compared to formulations solely based on vegetables. Moreover, the use of plant-based protein isolates has shown promising results, with potential to boost protein content, particularly when combined with cereals rich in essential amino acids (EAAs) (Arora et al., 2023; Dimina et al., 2022). Additionally, it’s worth mentioning that wheat, a commonly used ingredient in PBMA, serves as an additional protein source, further increasing the overall protein content of these alternative food products (Singh et al., 2021).

All PBMA included in this study were classified as ultra-processed. There is strong evidence linking frequent consumption of UPFs to poor health (Elizabeth et al., 2020) However, it is still unclear if ultra-processed PBMA has the same health impact as traditional UPF (Wickramasinghe et al., 2021). According to NOVA classification, UPFs can be defined as food formulations that include cosmetic ingredients and additives primarily for industrial use, aiming to mimic, mask, enhance, or restore sensory properties like texture, flavor, aroma, and color (Monteiro et al., 2019). In the case of PBMA, the objective is to mimic the meat-like sensory characteristics, physical and nutritional proprieties (Ahmad et al., 2022; Fiorentini et al., 2020). Therefore, the selection of ingredients is based on achieving these objectives (Ahmad et al., 2022; Fiorentini et al., 2020). The main ingredients used are plant-based protein sources like soybean, gluten, and wheat protein, being an affordable, functional, and high-protein food ingredient (Asgar et al., 2010). Additionally, flavors and food coloring agents are used to enhance the flavor and appearance of the product (Ahmad et al., 2022; Fiorentini et al., 2020). Fats and oils are used to obtain the juiciness, tenderness, and other sensory attributes of meat-like products (Kyriakopoulou et al., 2021).

It is worth noting that the NOVA food classification system, although widely used, has some controversies. One critical issue is that nutritionally balanced and unbalanced foods are grouped together (processed or ultra-processed) (Davidou et al., 2020; Vadiveloo and Gardner, 2023). For example, whole breads and breakfast cereals are classified as NOVA UPFs, despite their potential positive impact on nutrient intake (Gibney, 2023; Vadiveloo and Gardner, 2023). Other systems, such as SIGA, have been developed to address these disadvantages of the NOVA classification (Davidou et al., 2020). Some authors argue that the NOVA system is simplistic and fails to adequately evaluate the nutritional attributes of specific products like soy-based meat and milk alternatives (Messina et al., 2022).

For future assessments, conducting a multidimensional assessment, such as a nutritional profiling model, would be beneficial. This approach enables a broader comparison, facilitating a more accurate estimation of their overall impact on health. A study that employed two different dimensions to evaluate the healthiness of food, namely Nutri-Score and NOVA classification, products demonstrated that within the group of UPFs, differences were observed in nutritional quality (Galan et al., 2021). Studies that assessed the nutritional quality of PBMA compared to their meat counterparts employed this multidimensional approach, revealed that PBMA were better ranked nutrient profile models, such as the Health Star Rating and UK's Nutrient Profiling Model (Alessandrini et al., 2021; Curtain and Grafenauer, 2019). By incorporating different dimensions that impact health through distinct mechanisms, a more comprehensive assessment to evaluate the nutritional quality of products would be obtained.

This study has limitations, including the fact that the products assessed belong to a single retail chain, which may not represent the full range of products the fact that the collected data for the assessed products was obtained only from a single retail chain could be a limitation of the present study, as it may not fully represent the range of products available in the market. Additionally, assigning a value of 0.49 to products with <0.50 fiber and sugar levels on nutritional labels may not accurately reflect the nutrient content, potentially leading to an overestimation of the median contents.

However, we believe that one of the strengths of this study is its comprehensive assessment of the overall nutritional composition of PBMA compared to their MBP counterparts available in a major food chain retailer of the Portuguese market. Moreover, since most industrial food brands belong to multinational companies this picture has a strong probability of reflecting the global market. This work highlights important nutritional characteristics of the PBMA comparison to their meat counterparts, offering valuable insights to enhance the nutritional quality of both products. Furthermore, this study may guide future interventions aimed at reformulating industrial food products.

Scientific evidence indicates that a well-planned vegetarian diet can fulfill nutritional requirements of human nutrition. Therefore, when integrated into a balanced diet, plant-based alternatives can enhance overall nutrient intake, making it more practical and contributing to meeting the daily recommendations of some nutrients which can facilitate the transition and adherence to this dietary pattern. PBMA present a promising means to reduce meat consumption and promote more sustainable dietary patterns. However, it is crucial to carefully evaluate the nutritional adequacy and potential variations in nutritional composition when considering replacing traditional meat products with PBMA. Therefore, while our research highlights the most favorable nutritional profile for PBMA over MBP, it's crucial to understand that these alternatives shouldn't be seen as direct substitutes for meat products. Rather, they should be considered as part of a diverse and balanced diet. A study investigating the nutritional implications of replacing animal-based meat and milk with PBMA products revealed some concerns regarding potential nutritional inadequacies such as iodine, vitamin B12, zinc, and n-3 long-chain fatty acids among the Australian population (Lawrence et al., 2023). Therefore, considering the substitution purpose, when creating plant-based products that mimic meat products, it must be ensured that their composition is comparable or even better than their meat counterparts, especially regarding their sodium and sugar content. This could involve implementing fortification strategies or employing innovative production techniques to improve their nutrient content. In this regard, it is important to educate consumers on nutrition labelling, so that the easiest choice is plant-based products with reduced levels of fat, saturated fat, sugar, salt, and if possible, with the additional key of being fortified with nutrients like B12, iron, and zinc, which may be less prevalent in a plant-based diet.

This study has shown that plant-based alternatives can be a valuable part of a balanced and healthy diet. Nevertheless, comprehensive research encompassing various aspects of plant-based diets, such as multidimensional research on the nutritional profile of plant-based products, their long-term impact on health outcomes, and consumer behavior, is essential for a thorough understanding of their role in our diets.

5. Conclusion

In general, PBMA products exhibit higher fiber, carbohydrate and sugar content and lower levels of energy, total fat, saturated fat, and salt compared to their MBP counterparts. However, important variations across different categories were observed. Although plant-based products globally have a better nutritional profile, being plant-based does not automatically mean that it is better from a nutritional point of view than a similar meat-based product, since in specific product categories the nutritional profile of plant-based products is even worse than their meat-based counterparts. For example, PBMA burgers were found to be higher in energy, sugar, and salt. It is important to note that the nutritional composition of PBMA differs from their meat-based counterparts in most nutrients, indicating that they cannot be considered direct substitutes but rather a means to reduce meat consumption. All PBMA included in this study were classified as ultra-processed, it is an important sign that it is necessary for the food industry to invest in a less processed plant-based product profile, capable of promoting better health. However, not all ultra-processed products contain ingredients associated with a greater health risk and in this sense, it would be important to review the current classification system for ultra-processed foods. It is important recognize that some plant-based products classified as ultra-processed may still offer adequate nutritional profiles, without unnecessary additives and therefore may be integrated into a healthy plant-based diet.

Further research is crucial to better understand the long-term health effects of PBMA consumption, enabling more comprehensive guidance for consumers and policymakers.

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CRediT authorship contribution statement

Laila Sultan: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Patricia Padrao:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Marta Maganinho:** Writing – review & editing, Methodology, Investigation.

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

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2024.106390.

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