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Are plant-based alternatives healthier? A two-dimensional evaluation from nutritional and processing standpoints

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ABSTRACT

Background: Plant-Based Alternative Products (PBAPs) to meat and dairy are increasingly available. Their relative nutritional quality in comparison to animal-based homologs is poorly documented.
Objective: To characterize and evaluate the plant-based alternatives available on the market in Spain in comparison to animal products in terms of their nutritional composition and profile, and degree of processing.
Methods: Nutritional information for PBAPs and homologs were obtained from the Spanish 'Veggie base', branded food composition database. Five PBAPs categories (cheese, dairy products, eggs, meat, and fish, n = 922) were compared to animal-based processed (n = 922) and unprocessed (n = 381) homologs, using the modified version of the Food Standard Agency Nutrient Profiling System (FSAm-NPS score) and NOVA classification criteria.
Results: Compared to processed or unprocessed animal food, PBAPs contain significantly higher sugar, salt, and fiber. PBAPs for fish, seafood, and meat were lower in protein and saturated fatty acids. Overall, 68% of PBAPs, 43% of processed and 75% of unprocessed animal-homologs had Nutri-Score ratings of A or B (most healthy). About 17% of PBAPs, 35% of processed and 13% of unprocessed animal-based food were in Nutri-Score categories D or E (least healthy). Dairy, fish, and meat alternatives had lower FSAm-NPS scores (most healthy), while cheese alternatives scored higher (least healthy) than animal-based homologs. Unprocessed fish and meat were healthier than similar PBAPs based on FSAm-NPS criteria. Approximately 37% of PBAPs and 72% of processed animal-based products were ultra-processed food (NOVA group 4). Within the ultra-processed food group, Nutri-Score varied widely.
Conclusions: Most PBAPs had better nutrient profile than animal-based homologs. However, cheese, fish and meats PBAPs had poorer nutrient profile and were more processed. Given the high degree of processing and variable nutritional profile, PBAPs require a multi-dimensional evaluation of their health impact.

1. Introduction

Plant-based diets focus on foods derived from plant sources such as fruit, vegetables, grains, potatoes, legumes, nuts, and seeds. In recent years, the number of people following a plant-based eating style has increased, driven by concerns for animal welfare, environmental or health reasons (Hopwood et al., 2020; Onwezen et al., 2021). It has been estimated that following a plant-based dietary pattern could lead to a reduction in environmental impact by decreasing land, water and fertilizer use among other issues (Aleksandrowicz et al., 2016). Adopting a plant-based diet is considered as one of the essential strategies to fight climate change (Aleksandrowicz et al., 2016; Minx et al., 2017; World Health Organization, 2021) and loss of biodiversity, and support the sustainability of the planet (Aleksandrowicz et al., 2016).

Globally, the proportion of people following plant-based diet varies. For example, in Asia 19% of the population are vegetarian, whereas in North America or Europe, the prevalence is around 5% (Statista Research Department, 2016). According to the International Vegetarian

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Union, it is estimated that the tendency of increasing the consumption of plant-based food will continue growing in Western countries, and it was estimated that approximately 600 million people worldwide would have moved towards plant-based diet in 2019 (Fundación Vegetarianos Hoy, 2019).

Alongside the increased popularity of plant-based diets, there has also been an increase in the marketed availability of plant-based alternative products (PBAPs), especially for meat and dairy foods (Lawrence & Baker, 2019). PBAPs are food products that try to substitute those of animal origin without animal ingredients (Boukid, 2020; Onwezen et al., 2021).

A clear nutritional benefit of PBAPs is not evidenced in literature. Some PBAPs may have a poorer nutritional profile. For instance, plant-based meat alternatives are usually lower in protein (Alessandrini et al., 2021; Bryngelsson et al., 2022; Curtain & Grafenauer, 2019; Cutroneo et al., 2022; Pointke & Pawelzik, 2022; Romão et al., 2022). However, some PBAPs such as plant-based dairy alternatives with lower amount of sugar (Angelino et al., 2020; Clegg et al., 2021), and plant-based meat alternatives with lower saturated fat and higher fiber could also be healthier options compared those of animal origin (Alessandrini et al., 2021; Bryngelsson et al., 2022; Curtain & Grafenauer, 2019; Cutroneo et al., 2022; Pointke & Pawelzik, 2022; Romão et al., 2022). Other studies analyzing PBAP cheese alternatives showed similar results between both type of products in terms of total fat, protein and salt content (Craig et al., 2022; Fresán & Rippin, 2021; Pointke & Pawelzik, 2022). Given the wide variation in the relative nutrient content of PBAPs in comparison to their homologs it is important to study the overall nutrient profile holistically using a nutritional profiling system (for example the modified version of the Food Standard Agency Nutrient Profiling System -FSAm-NPS- score criteria).

While producing PBAPs, a primary aim of the food industry is to preserve the physical and sensory aspects of animal-based products as much as possible (Boukid, 2020; Onwezen et al., 2021). Achieving this goal through advance food processing techniques may at times compromise the nutritional quality of the PBAPs. (He et al., 2020; McClements & Grossmann, 2021). There is also accruing evidence to show that consuming ultra-processed foods can have deleterious health effects (de Miranda et al., 2021) and the degree of processing of PBAPs is poorly understood. Therefore, despite the promotion of PBAPs as being more nutritious and healthier alternatives (Hemler & Hu, 2019), the exclusion of animal ingredients *per se* may not necessarily mean that the respective PBAPs are healthy (Alcorta et al., 2021).

Given the concerns of nutritional quality and degree of processing, evaluating PBAPs on both these dimensions using appropriate criteria would provide new insights on their nutritional and health impacts. This facilitates the simultaneous evaluation of two important and complementary dimensions of food: namely its nutrient profile and level of processing that are related to health and disease (Romero Ferreiro et al., 2021). Few previous evaluations have focused on assessing the nutritional content or profiling of meat alternatives from Swedish, German and Italian online retail markets using the Nutri-Score algorithm (Bryngelsson et al., 2022; Cutroneo et al., 2022; Pointke & Pawelzik, 2022). However, the evaluation of the processing degree of PBAPs is limited. To the best of our knowledge, there is only a single study that mentioned that the processing degree of new meat PBAPs could make them ultra-processed food (NOVA 4) (Cutroneo et al., 2022). The agreement between nutritional profile and degree of processing of PBAPs to animal-based food has been poorly documented in literature. Therefore, we characterized and evaluated the plant-based alternatives available on the market in Spain in comparison to animal products in terms of their nutritional composition and profile, and degree of processing.

2. Methods

2.1. Study design

We conducted a descriptive and comparative study between PBAPs and their processed or unprocessed homologs of animal-origin.

2.2. Study products

A total of 2,790 PBAPs marketed in Spain included in the 'Veggie Base' data base (Babio et al., 2022) were classified into 15 categories and evaluated in this study. Five major categories of PBAPs (cheese, dairy products, eggs, meat, and fish) from Veggie Base (n = 922) were compared to their animal-based products (n = 922) and unprocessed animal-based food (n = 381) homologs (Fig. 1 **and Supplemental Table 1**).

2.3. Sampling for food products

The Veggie Base (Babio et al., 2022) includes PBAPs when nutritional information was obtainable through information made available by the food manufacturer through fact sheets or their official website or available for collection from nutritional food packaging labels in the period between February 2020 and December 2021. We selected 5 major PBAP categories with available animal homologs (cheese, dairy products, eggs, meat, and fish). These animal-based homologs were identified from the 5 supermarket websites according to their market share in Spain. (Supermercados: Cuota de Mercado En España En 2022 | Statista, n.d.) We then randomly selected from among the identified animal-based homologs to obtain the same sample size as the alternatives to enable appropriate comparison. Nutritional information of the selected animal-based homolog products were collected from own nutritional label products. In addition, nutritional information of unprocessed food (milk and yogurt, eggs, meat, fish and seafoods) was also collected from Spanish food composition tables (Farran et al., 2003; Ortega Anta et al., 2006).

2.4. Nutritional quality assessment

Nutrition information from the product label presented according to the mandatory nutritional declaration in EU Regulation 1169/2011 were analyzed for energy, carbohydrates, sugar, total fat, saturated fat, salt, protein, and the ingredients declared in the product labelling (Regulation (EU) No1169/2011 of the European Parliament and of the Council of 25 October 2011., 2011). The fiber content was assumed to be zero when it was not declared in the nutritional label.

2.5. Evaluation of nutrient profiles and degree of processing

Nutrient profile of the products was evaluated using the FSAm-NPS (modified version of the Food Standard Agency Nutrient Profiling System) score criteria, which underpins the Nutri-Score front-of-pack labelling criteria (Chantal & Hercberg, 2017). The FSAm-NPS score was computed by using the nutrient content per 100 g of product, using Nutri-Score calculation tool (Nutri-Score, 2022). The final FSAm-NPS score for each product was defined in a discrete continuous scale with a theoretical range of −15 (most healthy) to 40 (least healthy). The FSAm-NPS score was classified into 5 categories; from −15 to −1 (Category A, light green color), 0 to 2 (Category B, light green color), 3–10 (Category C, yellow color), 11 to 18 (Category D, Orange color), and 19 or higher (Category E, red color) (Chantal & Hercberg, 2017).

The processing degree of the products was assessed using the NOVA classification system (Monteiro et al., 2016; Monteiro, Cannon, Levy, et al., 2019). The NOVA system classifies food based on the degree of food processing (Monteiro et al., 2016) and has been most applied in scientific literature, globally (Monteiro, Cannon, Lawrence, et al., 2019).

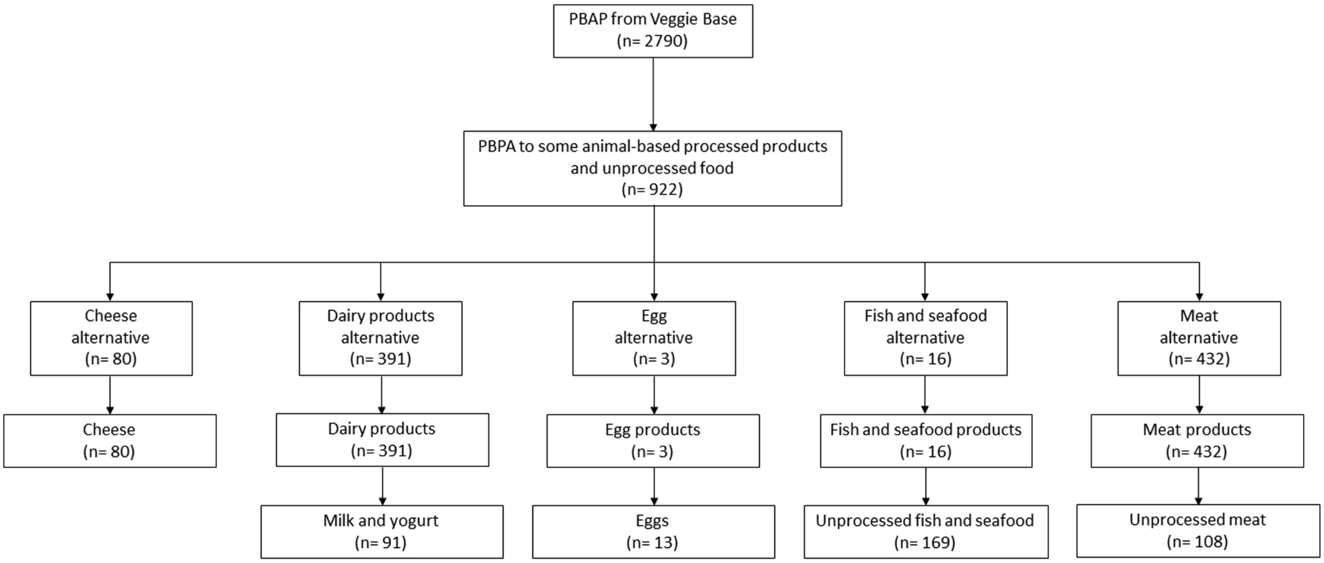

Fig. 1. Flow chart of plant-based alternative products included in Veggie Base and the study sample.Footnotes. Abbreviations: PBAP, Plant-Based Alternative Products. PBPA, Plant- Based Products Alternatives.

The NOVA classifies foods and drinks into four categories: unprocessed or minimally processed foods (group 1), processed culinary ingredients (group 2), processed foods (group 3), and ultra-processed foods (group 4) (Monteiro et al., 2011).

2.6. Statistical analyses

Descriptive data is reported as median [minimum; maximum] percentages (number) for continuous and categorical variables, respectively. Wilcoxon test and Kruskal-Wallis test were used to compare the FSAm-NPS and nutritional content between two or more categories, respectively. Chi-square was used to compare the distribution of Nutri-Score categories between PBAPs and unprocessed or processed animal-based food. The distribution of the overall FSAm-NPS or NOVA was computed in different PBAP groups and their animal-based counterparts and displayed using boxplots, including the median, 25th and 75th percentiles across NOVA and Nutri-Score categories. The ability of the Nutri-Score to discriminate the nutritional quality of products within categories was assessed using the number of available colors in each category. Discriminating performance was considered, when at least three classes of Nutri-Score were available for the food group. All analyses were performed using the software Stata/SE (version 14.0, StataCorp, College Station, TX). For all statistical tests, $P < 0.05$ was considered significant.

3. Results

The mean FSAm-NPS score of the 2790 PBAP included in 'Veggie Base' data base was 4.34 ± 7.80 points and the median [minimum; maximum] was 2 [-10;27]. Most PBAPs (31%) were classified under Nutri-Score A category.

Approximately, 68% (n = 622) of PBAPs, 43% (n = 395) of animal-based products and 75% (n = 285) of animal-based unprocessed food belonged to Nutri-Score A and B categories (most healthy). Seventeen percent (n = 158) of PBAPs, 34.8% of animal-based products (n = 321) and 13.1% (n = 50) of animal-based unprocessed food belong to Nutri-Score D and E categories (least healthy). With respect to NOVA classification system, a total of 12.6% (n = 116) of the PBAPs, 15% (n = 138) of animal-based products and 100% (n = 381) of animal-based unprocessed food were categorized as NOVA 1. A total of 36.5% (n = 337) of the PBAPs and 71.7% (n = 661) of animal-based products were classified as ultra-processed (NOVA 4). Most PBAPs were classified in NOVA 3 (43.4%; n = 400) (Table 1).

Table 2 shows the median energy, nutrient composition (for 100 g of product), the FSAm-NPS scores, the Nutri-Score categories as well as distribution of the NOVA classification for the 15 categories of PBAPs included in the 'Veggie Base'. Among the 15 categories of PBAP studied, 75.8% (n = 2114) of the products were classified into Nutri-Score categories A and B, 8.14% (n = 227) in category C and 16.1% (n = 449) in categories D and E. In terms of the NOVA classification, 9% (n = 251) of the products were categorized as NOVA 1, 5.91% (n = 165) were processed culinary ingredients (NOVA 2), 48.82% (n = 1362) as processed food (NOVA 3) and 36.27% (n = 1012) as ultra-processed (NOVA 4).

A comparison of the median energy and nutrient composition (for 100 g of product), FSAm-NPS score, Nutri-Score category between PBAPs and their processed and unprocessed animal-based homologs is presented in Table 3.

Compared to animal-based cheese, plant-based cheese alternatives had significantly higher FSAm-NPS score (less healthy), lower amount of total fat, saturated fat and protein and significantly higher content in salt, fiber, % of fruits, vegetables, legumes, nuts and oils (Table 3). Cheese alternatives and animal-based cheese were predominantly (40%) classified as belonging to Nutri-Score category E (Table 1).

On the contrary, dairy products alternatives had significantly lower FSAm-NPS scores (most healthy) compared to their animal-based processed and unprocessed dairy products. Compared to animal-based dairy products, plant-based dairy alternatives presented significantly lower content of saturated fat, and salt. Milk and yogurt had significantly lower content of total fat, fiber, % of fruit, vegetables, legumes, nuts, and oils than dairy product alternatives. (Table 3).

Plant-based egg alternatives (66%) were more likely to belong to Nutri Score category B, while processed egg products were healthier and placed in Nutri-Score category A (66%). Regular eggs were most likely to be classified under Nutri-Score A (38%) and B (38%) categories (Table 1). It is noted that plant-based egg alternatives were significantly higher in sugar, sodium and % of fruits, vegetables, legumes, nuts, and oils than animal-based processed and unprocessed egg (Table 3).

Plant-based fish and seafood alternatives were often (50%) placed in Nutri-Score A category. While processed fish and seafood products fared poorer on the Nutri-Score category with 44% of them classified under Nutri-Score C category, unprocessed fish and seafood had better nutritional profiles and 73% of them belonged to A Nutri-Score category (Table 1). This was because unprocessed fish and seafood contain significantly lower amount of energy, sugar, total fat, saturated fat, salt,

Table 1
Classification of plant-based products alternatives versus their animal-based products or unprocessed animal-based foods according to Nutri-Score and NOVA nutrient profiling system.

Products type	Nutri-Score %(number)					NOVA %(number)			
	A	B	C	D	E	1	2	3	4
Cheese alternatives (n = 80)	**0.0 (0)**	**11.3 (9)**	**21.3 (17)**	**27.5 (22)**	**40.0 (32)**	**0.0 (0)**	**8.8 (7)**	**52.5 (42)**	**28.4 (31)**
Cheese (n = 80)	**1.3 (1)**	**0.0 (0)**	**7.5 (6)**	**85.0 (68)**	**6.3 (5)**	**1.3 (1)**	**0.0 (0)**	**32.9 (25)**	**65.2 (50)**
Dairy products alternatives (n = 391)	**28.6 (112)**	**54.2 (212)**	**6.4 (25)**	**10.5 (41)**	**0.3 (1)**	**18.2 (71)**	**8.7 (34)**	**44.8 (175)**	**28.4 (111)**
Dairy products (n = 391)	**18.0 (78)**	**60.6 (237)**	**15.6 (61)**	**3.3 (13)**	**0.5 (2)**	**34.8 (136)**	**0.0 (0)**	**18.2 (71)**	**47.1 (184)**
Milk and yogurt (n = 91)	**25.3 (23)**	**37.4 (34)**	**24.2 (22)**	**4.4 (4)**	**8.8 (8)**	**58.3 (91)**	**0.0 (0)**	**0.0 (0)**	**0.0 (0)**
Egg alternatives (n = 3)	0.0 (0)	66.7 (2)	33.3 (1)	0.0 (0)	0.0 (0)	**0.0 (0)**	**0.0 (0)**	**0.0 (0)**	**100.0 (3)**
Egg products (n = 3)	66.6 (2)	0.0 (0)	33.3 (1)	0.0 (0)	0.0 (0)	**0.0 (0)**	**0.0 (0)**	**0.0 (0)**	**100.0 (3)**
Eggs (n = 13)	38.5 (5)	38.5 (5)	7.7 (1)	7.7 (1)	7.7 (1)	**92.3 (12)**	**0.0 (0)**	**7.7 (1)**	**0.0 (0)**
Fish and seafood alternatives (n = 16)	**50.0 (8)**	**6.3 (1)**	**43.8 (7)**	**0.0 (0)**	**0.0 (0)**	**0.0 (0)**	**0.0 (0)**	**6.3 (1)**	**93.8(15)**
Fish and seafood products (n = 16)	**12.5 (2)**	**31.3 (5)**	**43.8 (7)**	**12.5 (2)**	**0.0 (0)**	**6.3 (1)**	**0.0 (0)**	**0.0 (0)**	**93.8 (15)**
Unprocessed fish and seafood (n = 169)	**72.8 (123)**	**13.6 (23)**	**7.1 (12)**	**6.5 (11)**	**0.0 (0)**	**100.0 (169)**	**0.0 (0)**	**0.0 (0)**	**0.0 (0)**
Meat alternatives (n = 432)	**42.8 (185)**	**21.5 (93)**	**21.3 (92)**	**13.7 (59)**	**0.7 (3)**	**10.4 (45)**	**6.5 (28)**	**42.1 (182)**	**41.0 (177)**
Meat products (n = 432)	**2.31 (10)**	**13.9 (60)**	**30.3 (131)**	**46.8 (202)**	**12.5 (29)**	**0.0 (0)**	**0.0 (0)**	**5.32 (23)**	**94.7 (409)**
Unprocessed meat (n = 108)	**54.6 (59)**	**12.0 (13)**	**8.3 (9)**	**20.4 (22)**	**4.6 (5)**	**100.0 (108)**	**0.0 (0)**	**0 (0)**	**0.0 (0)**

In bold font we represent significant differences ($p < 0.05$) in the comparison of Nutri-Score categories and NOVA between PBAP, animal-based products and unprocessed.
Animal-based foods of the different products type using Chi-square test.

fiber, % of fruits, vegetables, a higher amount of protein than plant-based fish and seafood alternatives. Unprocessed fish and seafood had a lower (most healthy) FSAm-NPS score in relation to plant-based fish and seafood alternatives and processed fish and seafood products.

Most meat alternatives, meat products and unprocessed meat were placed in A, D and A Nutri-Score categories, respectively (Table 1). Unprocessed meat contains significantly lower contents of energy, sugar, salt, fiber, % of fruits and vegetables, and a higher content of saturated fat and protein than meat alternatives. The distribution of the FSAm-NPS score according to the different Nutri-Score categories within each evaluated PBAP category and their animal-based products or food counterparts is displayed in Fig. 2. The boxplot shows the discrimination capacity of the Nutri-Score in classifying each of the product categories studied. Discriminating performance of the Nutri-Score could be evaluated for all categories of PBPAs, except eggs. This was because while there was a distribution of products across 3 or more categories of Nutri-Scores for all categories except eggs. PBAPs of cheese, fish and seafoods and meat categories varied widely in their nutritional quality. Plant-based cheese alternatives had Nutri-Score category ratings ranging between C and E. Fish and seafoods alternatives and meat alternatives also varied between Nutri-Score categories A and C. Dairy alternatives were all consistently placed within category B of Nutri-Score.

Fig. 3 shows the distribution of the FSAm-NPS score of the study food (unprocessed animal-based food, plant-based alternatives products and animal-based products) according to the NOVA classification system criteria. Within food and products classified as ultra-processed (NOVA group 4), there was a wide variation of Nutri-Score. A total of 37.7% (n = 127), 24% (n = 81), 18.7% (n = 63), 15.1% (n = 51) and 4.45% (n = 15) of ultra-processed PBAPs (NOVA 4) were allocated A, B, C, D and E Nutri-Score categories. The ultra-processed PBAPs placed in healthier categories of Nutri-Score A and B categories were dairy (n = 88) and meat alternatives (n = 107) (data are not shown). Similarly, among ultra-processed animal-based products, a total of 9.08% (n = 60), 19.5% (n = 129), 27.8% (n = 184), 39.2% (n = 259) and 4.4% (n = 29) were allocated A, B, C, D and E Nutri-Score categorical ratings.

4. Discussion

In this study, we evaluated using evidence-based metrics, two important and complementary nutrition and health-related dimensions of PBPAs and compared its performance in relation to processed and unprocessed animal-based homologs. To the best of our knowledge, this is the first study to perform a two-dimensional assessment of the nutritional profile and degree of processing of a large sample of PBAPs marketed in Spain. We assessed the nutrient profile using the FSAm-NPS algorithm and the degree of processing using the NOVA classification system. FSAm-NPS focuses on the nutritional dimension of a food but does not cover other health dimensions of food (food processing, additive content, presence of pesticides, etc.). NOVA on the other hand focuses on the level of processing but does not evaluate the nutrient profile of the food it classifies. Therefore, it is important to consider ways to evaluate complementary dimensions of food and food products, the complexity of which requires innovative assessment strategies to overcome the challenges posed by reductionist approaches.

We found evidence that contradicted the general belief that plant based alternatives are always healthier alternatives to animal-based food products. For example, our results showed that currently available plant-based cheese in Spain were usually lower in protein and total fat but higher in salt/sodium compared to those of animal origin, in agreement with other studies (Craig et al., 2022; Fresán & Rippin, 2021; Pointke & Pawelzik, 2022). Saturated fat content has been found to vary according to the main ingredient used. For example, those cheese PBAP including nuts, in line with our results, usually were lower in saturated fat compared to cheese from animal origin. In contrast, plant-based cheese including coconut butter presented higher amount of saturated fat (Boukid et al., 2021; Craig et al., 2022; Fresán & Rippin, 2021).

In case of dairy, in line with existing studies, our study revealed that plant-based alternatives contained higher total fat and fiber and lower protein and saturated fat compared to their animal-based homologs (Angelino et al., 2020; Clegg et al., 2021). In our study, the amount of sugar in plant-based dairy alternatives and milk and yogurts of animal origin were comparable. This contradicts findings from UK (Clegg et al., 2021) and Italy (Angelino et al., 2020) that reported a lower amount of sugar in plant-based dairy alternatives. Unlike our results, these studies showed that soy dairy products had a higher protein content than other plant-based beverages.

Evidence comparing egg and fish products of plant and animal origin is scarce probably because their availability in the market is limited. We only found one study evaluating different types of seafood PBAPs (Boukid et al., 2022) which showed that some plant-based alternatives of these products had lower salt content unlike our results. However, our results agreed with the aforementioned study and adds further evidence to document that plant-based seafood were usually lower in protein and saturated fat compared to their animal counterparts.

Meat alternatives are products garnering the most scientific interest because of their popularity. Our findings in relation to the nutritional composition of a large number of meat alternatives are in line with earlier showing lower protein and saturated fat and higher in fiber

Table 2
Median Energy and nutrient composition (per 100 g of product), FSAm-NPS scores, Nutri-Score category, and distribution of products across NOVA groups of different plant-based products alternative (PBAP) included in Veggie Base (n = 2790 products).

PBAP	Energy (kcal) Median [min; max]	Sugar (g) Median [min;max]	Total Fat (g) Median [min; max]	SFA (g) Median [min;max]	Salt (g) Median [min; max]	Protein (g) Median [min; max]	Fiber (g) Median [min;max]	F, V, L, N, and oils from OO, RO, and WO (%) Median [min;max]	FSAm-NPS score Median [min;max]	Nutri-Score category Median	NOVA classification % (number)			
											1	2	3	4
Cereals and derivatives (n = 694)	378 [12;607.7]	4 [0;76]	6.45 [0.06;50.8]	1.2 [0;48]	0.05 [0;3.3]	8.6 [0;60]	4 [0;45]	0 [0;84]	0 [-7;25]	B	5.2 (36)	4.03 (28)	52.4 (364)	38.3 (266)
Cheese alternatives (n = 80)	285 [170;507]	0.5 [0;16]	22.5 [10;44]	15 [0.9;23]	1.67 [0;3.5]	2.25 [0;15.4]	0 [0;8.4]	0 [0;90]	17 [0;23]	D	0 (0)	8.75 (7)	52,5 (42)	38.7 (31)
Dairy alternatives (n = 391)	63 [12;378]	6.1 [0;50.2]	2.1 [0;23.6]	0.3 [0;17]	0.1 [0;1.5]	2 [0.1;62]	0.4 [0;15]	0 [0;51.9]	1 [-6;19]	B	18.2 (71)	8.7 (34)	44.8 (175)	28.4 (111)
Egg alternatives (n = 3)	152 [152;348]	1,2 [1,2;3,6]	6,7 [3,2;6,7]	0,8 [0,6;0,8]	0.76 [0.76;2.5]	3,4 [3,4;15]	0 [0;16]	56,0 [0,0; 61,0]	1,0 [0,0;9,0]	B	0 (0)	33.3 (1)	33.3 (1)	33.3 (1)
Fish alternatives (n = 16)	95 [21;180]	1 [0;3]	3.75 [0;12]	0,5 [0,0;3,0]	0.9 [0;3.4]	9 [0,2;20,0]	1,0 [0,0;7,0]	0 [0,0; 0,0]	0,0 [-5,0;10,0]	B	0 (0)	12.5 (2)	50 (8)	37.5 (6)
Fruits based products (n = 90)	153.5 [54;688]	27 [0;75.2]	0.5 [0.05;67]	0.1 [0;63]	0.03 [0;1]	0.9 [0;12.2]	0 [0;17]	99 [0;100]	1 [-7;18]	B	6.7 (6)	7.8 (7)	58.9 (53)	26.7 (24)
Legumes based products (n = 71)	253.4 [17;370]	1.5 [0;6.1]	6.5 [0;27]	1 [0;4.9]	0.7 [0;1.5]	6.9 [0.7;50]	4.4 [0;15.5]	0 [0;56.1]	-1 [-9;7]	A	7.04 (5)	7.04 (5)	60.5 (43)	25.3 (18)
Meat alternatives (n = 432)	200.5 [12;454]	1.52 [0;19]	10 [0.1;47]	1.3 [0;19]	1.2 [0;16]	14 [0.7;54]	2.3 [0;94]	0 [0;90]	1 [-9;24]	B	10.4 (45)	6.5 (28)	42.1 (182)	40.9 (177)
Nuts and seeds (n = 66)	597 [154;697]	3,7 [0;58]	49.1 [1.5;67]	5.95 [0;30]	0.03 [0;2.7]	20.7 [2.7;46]	0 [0;36]	0 [0;100]	9 [-9;24]	C	4.5 (3)	9.1 (6)	40.9 (27)	45.4 (30)
Pre-cooked products (n = 193)	120 [1.2;518.6]	1.8 [0;30.4]	4.1 [0;64]	0.5 [0;25.8]	0.9 [0;3.7]	4.4 [0.1;23]	1.3 [0;9.2]	0 [0;88]	1 [-7;27]	B	3.6 (7)	4.15 (8)	49.2 (95)	43.01 (83)
Sauces and condiments (n = 161)	163 [0;895]	2.7 [0;57]	9 [0;92]	1.1 [0;33]	1.2 [0;50.7]	1.8 [0;37]	0.3 [0;31.7]	0 [0;100]	8 [-6;27]	C	6.21 (10)	1.83 (3)	45.3 (73)	46.5 (75)
Snacks (n = 120)	252.5 [49;698.3]	2 [0;67.4]	19.25 [0.2;67.5]	2.95 [0;64.1]	1.21 [0;5.5]	5.3 [1.11;14.2]	0 [0;20.1]	0 [0;84]	11 [-5;23]	D	5 (6)	0.83 (1)	48.3 (58)	45.8 (55)
Sweets (n = 234)	480 [41;689]	31 [0;80]	26 [0;68]	5.9 [0;64]	0.02 [0;1.3]	6.8 [0;34]	4.3 [0;45]	0 [0;100]	13 [-6;27]	D	14.1 (33)	12.8 (30)	53.4 (125)	19.6 (46)
Vegetable fats (n = 15)	675 [351;900]	0 [0;0.5]	75 [39;100]	17 [9.2;]	0 [0;0.49.0]	0 [0;1.7]	0 [0;0]	0 [0;2]	19 [15;20]	E	46.6 (7)	0 (0)	46.6 (7)	6.6 (1)
Vegetable based products (n = 224)	45 [1;416]	1.7 [0;23]	1 [0;35]	0.2 [0;3.1]	1.4 [0;43.0]	1.4 [0;43.0]	1.4 [0;84]	0 [0;100]	1 [-10;13]	B	9.8 (22)	2.2 (5)	48.6 (109)	39.2 (88)

Abbreviations: SFA, Saturated Fatty Acids; F, Fruits; V, Vegetables; L, Legumes; N, Nuts; OO, Olive oil; PBAP, plant-based products alternative some animal-based food; RO, Rapeseed oil; WO, Walnut oil; FSAm-NPS: modified version of the Food Standard Agency Nutrient Profiling System.

Table 3
Energy, nutrient composition (for 100 grams of product) of the FSAm-NPS score profile, Nutri-Score and its categories of different categories of plant-based products alternatives (PBAP) versus their animal-based processed products and unprocessed food.

Products type	Energy (kcal) Median [min; max]	Sugar (g) Median [min;max]	Total Fat (g) Median [min;max]	SFA (g) Median [min;max]	Salt (g) Median [min;max]	Protein (g) Median [min;max]	Fiber (g) Median [min;max]	F, V, L, N, and oils from OO, RO, and WO (%) Median [min;max]	FSAm-NPS score Median [min;max]	Nutri-Score category Median
Cheese alternatives (n = 80)	285 [170;507]	0.5 [0;16]	**22.5 [10;44]**	**15.0 [0.9;23]**	**1.67 [0.0;3.5]**	**2.25 [0;15.4]**	**0.0 [0;8.4]**	**0.0 [0;90]**	**17 [0;23]**	**D**
Cheese (n = 80)	314.3 [47.1;443.1]	1.0 [0.0;4.7]	**26.7 [0.4;40.0]**	**19.0 [0.3;27.0]**	**1.2 [0.0;2.7]**	**18.5 [0.26;32.0]**	**0.0 [0.0;0.01]**	**0.0 [0.0;0.0]**	**14.0 [-4.0;21.0]**	**D**
Dairy products alternatives (n = 391)	**63 [12.0;378]**	6.1 [0.0;50.2]	**2.1 [0.0;23.6]**	**0.3 [0.0;17.0]**	**0.1 [0.0;1.5]**	**2.0 [0.1;62.0]**	**0.4 [0.0;15.0]**	**0.0 [0.0;51.0]**	**1.0 [-5.0;21.0]**	**B**
Dairy products (n = 391)	**58.6 [23.7;338.7]**	4.8 [2.8;39.8]	**1.6 [0.0;36.0]**	**1.1 [0.0;24.0]**	**0.13 [0.0;2.0]**	**3.2 [0.4;16.0]**	**0.0 [0.0;4.0]**	**0.0 [0.0;35.0]**	**1.0 [-5.0;19.0]**	**B**
Milk and yogurt (n = 91)	**65.9 [31.2;525.0]**	5.6 [2.2;54.4]	**1.9 [0.1;27.1]**	**1.1 [0.0;16.2]**	**0.12 [0.0;1.7]**	**3.7 [0.6;36.1]**	**0.0 [0.0;1.9]**	**0.0 [0.0;0.0]**	**1.0 [-3.0;26.0]**	**B**
Egg alternatives (n = 3)	152.4 [152.4;349.4]	**1.2 [1.2;3.6]**	6.7 [3.2;6.7]	0.8 [0.6;0.8]	**0.76 [0.76;2.5]**	3.4 [3.4;15.0]	0.0 [0.0;16.0]	**56.0 [0.0; 61.0]**	1.0 [0.0;9.0]	B
Egg product (n = 3)	119.5 [46.7;283.9]	**0.0 [0.0;0.0]**	8.0 [0.2;25.0]	2.5 [0.1;7.5]	**0.4 [0.1;0.4]**	11.5 [11.5;15.0]	0.0 [0.0;0.0]	**0.0 [0.0; 0.0]**	-1.0 [-4.0;5.0]	A
Eggs (n = 13)	162.0 [44.0;353.0]	**0.4 [0.0.0.7]**	11.8 [0.0;31.9]	3.1 [0.0;9.5]	**0.33 [0.12;0.69]**	13.0 [10.0;16.5]	0.0 [0.0;0.0]	**0.0 [0.0;0.0]**	0.0 [-4.0;24.0]	B
Fish and seafood alternatives (n = 16)	**130.4 [21.0;204.0]**	**1.0 [0.0;3.0]**	**3.7 [0.0;12.0]**	**0.5 [0.0;3.0]**	**0.9 [0.0;3.4]**	**9 [0.2;20.0]**	**1.0 [0.0;7.0]**	0.0 [0.0; 0.0]	**0.0 [-5.0;10.0]**	**B**
Fish and seafood products (n = 16)	**213.7 [95.1;290.1]**	**1.3 [0.0;3.5]**	**11.6 [1.1;27.2]**	**2.5 [0.1;7.5]**	**0.13 [0.0;2.1]**	**9.3 [5.3;19.0]**	**0.0 [0.0;2.7]**	0.0 [0.0; 0.0]	**3.5 [-1.0;14.0]**	**C**
Unprocessed fish and seafood (n = 169)	**98.3 [36.2;284.2]**	**0.0 [0.0;4.8]**	**1.9 [0.2;24.5]**	**0.43 [0.0;21.0]**	**0.26 [0.04;4.7]**	**18.1 [6.3;32.5]**	**0.0 [0.0;2.1]**	0.0 [0.0;0.0]	**-3.0 [-5.0;16.0]**	**A**
Meat alternatives (n = 432)	**201 [12.0;454.0]**	**1.52 [0.0;19.0]**	9.7 [0.1;47.0]	**1.3 [0.0;19.0]**	**1.2 [0.0;16.0]**	**14.0 [0.7;54.0]**	**2.4 [0.0;94.0]**	**0.0 [0.0; 90.0]**	**1.0 [-9.0;25.0]**	**B**
Meat products (n = 432)	**189.5 [26.0;504]**	**0.6 [0.0;21.0]**	10.9 [0.0;55.0]	**3.5 [0.0;18.0]**	**1.6 [0.0;15.0]**	**16.0 [0.0;63.0]**	**0.0 [0.0;14.0]**	**0.0 [0.0; 50.0]**	**11.0 [-6.0;25.0]**	**D**
Unprocessed meat (n = 108)	**156.9 [88.3;682.0]**	**0.0 [0.0;3.7]**	8.4 [1.0;71.0]	**2.7 [0.3;30.0]**	**0.18 [0.08;3.67]**	**20.2 [4.1;32.3]**	**0.0 [0.0;06]**	**0.0 [0.0;0.0]**	**-1.0 [-4.0;26.0]**	**A**

Abbreviations: SFA, Saturated Fatty Acids; F, Fruits; V, Vegetables; L, Legumes; N, Nuts; OO, Olive oil; RO, Rapeseed oil; WO, Walnut oil; FSAm-NPS: modified version of the Food Standard Agency Nutrient Profiling System. In bold font significant differences ($p<0.05$) using Kruskal-Wallis test and Wilcoxon test are showed.

content compared those of animal origin (Alessandrini et al., 2021; Bryngelsson et al., 2022; Curtain & Grafenauer, 2019; Cutroneo et al., 2022; Pointke & Pawelzik, 2022; Romão et al., 2022). We also found that meat PBAPs available in Spain showed higher salt content than their animal counterparts, as has been also reported elsewhere (Alessandrini et al., 2021; Bryngelsson et al., 2022; Curtain & Grafenauer, 2019; Pointke & Pawelzik, 2022; Romão et al., 2022). However, it is noted that Cutroneo and coworkers reported that PBAP cured meat alternatives had lower salt content (Cutroneo et al., 2022).

Our findings agree with the three earlier studies that analyzed the nutrition profile and showed that most meat PBAPs are placed in Nutri-Score categories A, B (most healthy) and C (middle category) (Bryngelsson et al., 2022; Cutroneo et al., 2022; Pointke & Pawelzik, 2022). In addition, cheese alternatives were often in D or E Nutri-Score categories similar to the findings from Germany study (Pointke & Pawelzik, 2022).

Previous evaluation of the processing degree of PBAPs is limited. In our study 41% of these products were ultra-processed as per the NOVA classification. This compares more favorably to the results from the only available smaller study that suggested that almost all of new meat PBAPs could be classified as ultra-processed without a formal evaluation using the NOVA criteria (Cutroneo et al., 2022). The high degree of processing in PBAPs is expected given that PBPAs are frequently ultra-processed to try to simulate from the sensory and organoleptic point of view as best as possible those products of animal origin, such as meat, fish, milk, and eggs. To acquire taste and smell characteristics of foods of animal origin, salt, sugar, aromatic herbs, and flavorings are added. To create a similar visual appeal, colorants and other ingredients are used. In case of texture, thickeners, gelling agents, carbohydrates, and oil emulsions are used (McClements & Grossmann, 2021).

Our results show that most of the PBAPs marketed in Spain and included in the Veggie database were classified into Nutri- Score categories A and B (most healthy) but are however placed in categories 3 and 4 of the NOVA system (processed and ultra-processed products). These findings justify the need for a two-dimensional approach we undertook in this study. For example, even though most of PBAPs from the nutritional profile point of view are better that those of animal origin, most of them could be considered ultra-processed products and have several additives. However, in some cases PBAPs (i.e. fish and meat) showed a worse nutritional quality than their unprocessed animal counterparts according to the Nutri-Score system because the latter usually have lower amounts of salt and higher amounts of protein. The argument for a concurrent evaluation of the nutrient profile and degree of processing is supported by recent efforts that evaluated the impact of Nutri-Score 2.0. Nutri Score 2.0 apart from identifying the nutrient profile using the

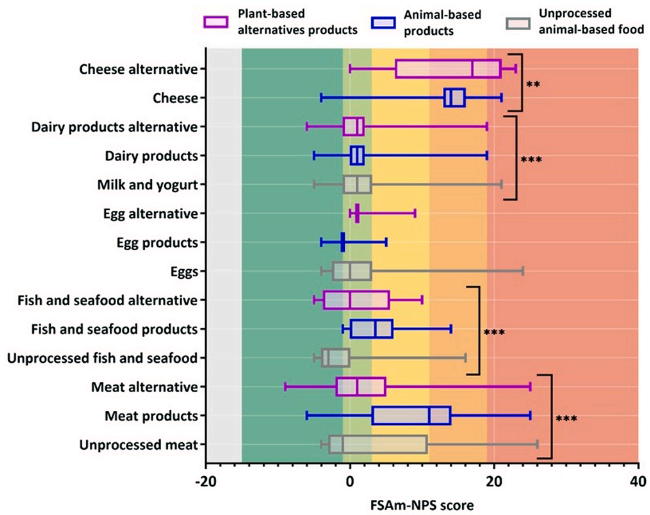

Fig. 2. Boxplot of the distribution of study PBAP categories FSAm-NPS score versus their animal-based counterparts and unprocessed food. **Footnotes** Abbreviations: FSAm-NPS: modified version of the Food Standard Agency Nutrient Profiling System. Asterisks indicate comparisons between food groups using the Kruskal-Wallis and Wilcoxon test, as appropriate, and the statistical significance: *, $P < 0.05$; **, $P \leq 0.01$; ***, $P < 0.001$. Vertical lines represent the cut-offs of the Nutri-Score categories. The boundary of the box nearest to the right indicates the 25th percentile, the line within the box marks the median, and the boundary of the box furthest from the right indicates the 75th percentile. Colors: dark green (FSAm-NPS score − 15 to − 1), light green (FSAm-NPS score 0 to 2), yellow (FSAm-NPS score 3 to 10), orange (FSAm-NPS score of 11–18), and red (FSAm-NPS score 19–40).

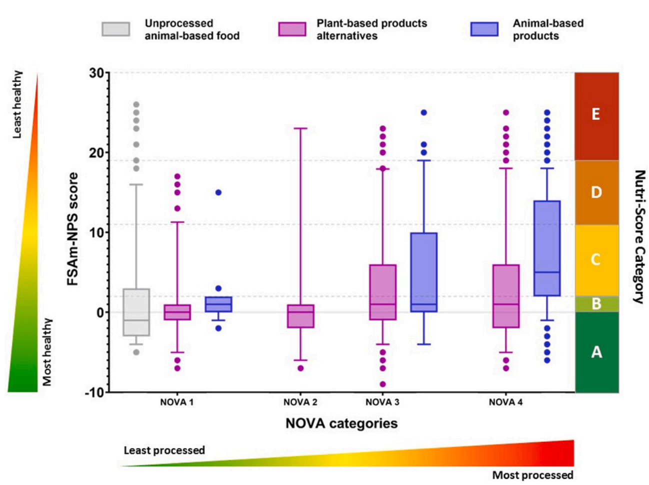

Fig. 3. Boxplot of the distribution of the FSAm-NPS score of the evaluated food and products according to the NOVA classification system criteria. **Footnotes** Abbreviations: FSAm-NPS: modified version of the Food Standard Agency Nutrient Profiling System. The boundary of the box nearest to the bottom indicates the 25th percentile, the line within the box marks the median, and the boundary of the box furthest from the top indicates the 75th percentile. Whiskers indicate of 5th and 95 percentiles. Colors: dark green (FSAm-NPS score − 15 to − 1), light green (FSAm-NPS score 0 to 2), yellow (FSAm-NPS score 3 to 10), orange (FSAm-NPS score of 11–18), and red (FSAm-NPS score 19–40).

conventional categories on front-of pack label, also included a banner to indicate if the evaluated product was an ultra-processed food. This new and improved graphical label was able to facilitate identification and comprehension of the two complementary nutrition and health dimensions of food in a group of 21,159 participants in the NutriNet Sante cohort (Srour et al., 2022).

Although there is no international consensus on the definition of what is an ultra-processed food, the NOVA classification is one of the most accepted (Moubarac et al., 2014). Furthermore, ultra-processed food consumption has been associated with an increased risk of non-communicable diseases such as overweight and obesity, type 2 diabetes, cardiovascular diseases, certain locations of cancer and total mortality (Lane et al., 2021). Hence, a health impact evaluation of an excessive consumption of these novel and emerging ultra-processed PBAPs is warranted. In the meantime, it would seem prudent to moderate the consumption these food products and prioritize the consumption of unprocessed plant-based food.

Our study has several strengths that deserve to be mentioned. First, it should be noted that this is the first study assessing at the same time the nutritional composition, the Nutri-Score profile, and the degree of processing of different PBAPs marketed in Spain. Second, a large number and variety of PBAPs were analyzed. However, we also acknowledge some limitations. First, although the collection of data on PBAPs was methodical and extensive, it is likely that not all the PBAPs marketed in Spain and their respective animal-derived counterparts have been included in the analysis. Second, the nutritional food information was not derived from direct chemical analysis, but from the mandatory declaration of nutritional information in the labels of these products. The assumption of null fiber content in several PBAPs is a limitation of this analysis and could have underestimated the fiber content for the plant-based alternatives. However, it should be emphasized that nutritional information through commercial labeling constitutes a key source of information given the lack of composition tables for this type of products. These findings also emphasize the utility of specialized food composition databases such as the Veggie base in supporting healthy food choices (Gibney, 2019). Finally, there is a need to periodically update such data bases to keep the information current. Furthermore, since a shift to a more plant-based diet stems from its positive impact on the environment and sustainability (Willett et al., 2019), future evaluations should also compare the environmental footprint of the products.

It is important to highlight a potential limitation because several of these processed products and their plant-based alternatives and mainly unprocessed foods could be prepared with added salt or fat. Therefore, our result must interpret cautiously taking into account this potential underestimation in salt and fat from unprocessed food after preparation, bearing in mind that dietitians could individualize and advice the dietary modification accordingly.

4.1. Conclusions

The majority of PBAPs (fish and meat) presented a better or similar (dairy) nutritional profile compared to their animal-based counterpart products. However, most PBPAs analyzed were highly processed. When compared to unprocessed food counterparts, PBAPs were less healthy due to their high content total fat (dairy, fish and meat categories), and salt (fish and meat categories). It is important to stress that the nutritional value enormously varies among different PBAPs and therefore require a multi-dimensional assessment such as the one used in this analysis. These findings also suggest a scope for innovation by the food industry to improve the formulation of these products in terms of processing and nutritional composition. Future research is needed to prospectively assess the potential effects of these products on health.

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CRediT authorship contribution statement

Sara de las Heras-Delgado: Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Sangeetha Shyam:** Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Èrica Cunillera:** Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Natalia Dragusan:** Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Jordi Salas-Salvadó:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Nancy Babio:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

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 used were avalaible in Veggie base data base, which was published for Publicacions URV http://publicacions.urv.cat/cataleg/altres-titols/15-cataleg/altres-titols/959-veggiebase

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Appendix A. Supplementary data

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