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ORIGINAL PAPER

Seafood alternatives: assessing the nutritional profile of products sold in the global market

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Abstract
The global market for seafood alternatives is witnessing an exponential growth. Nevertheless, the nutritional quality of such products is scarcely studied. Thus, this study aimed to evaluate, for the first time, the nutritional quality of seafood alternatives launched in the global market from 2002 to 2021 and to compare them with the conventional seafood products. Using the Mintel Global New Products Database, the nutritional information of seafood alternatives (i.e., tuna, shrimps, calamari, fish fingers, fish sticks, salmon, caviar, and fillet) was retrieved, and compared with conventional products. A total of 149 seafood alternatives were identified, of which 83 items had complete mandatory nutritional labeling. Conventional products ($n = 973$) were also collected, from which 130 products have a complete nutritional labeling. Results revealed that tuna, shrimps, caviar and fillet alternatives contained significantly less protein than conventional products, while calamari, fish fingers, fish sticks and salmon alternatives had similar amounts to their conventional counterparts. Salt content was significantly higher in tuna, fish fingers and sticks substitutes, but lower in shrimps, calamari and caviar alternatives compared to conventional products. Overall, the commercially available seafood alternatives have nutritional strengths and some shortcomings to be further addressed in future research such as low protein content. Additionally, fortification of seafood alternatives with micronutrients, such as omega-3 fatty acids and vitamins (A, B, and D), should be considered to ensure a nutritional equivalence with the conventional products.

Keywords Plant-based diet · Vegan · Vegetarian · Nutrients · Micronutrients · Future food

Introduction

Plant-based diets have are becoming popular based on several arguments such as health benefits, environmental sustainability, and ethical merit against animal-based foods [1]. Thus, the demand of non-animal food products is increasing and this tendency has created new opportunities for the food industry [2]. Non-animal sources, including cereals, vegetables, pulses, nuts, seaweed, microalgae, and fungi, are versatile and offer high flexibility for designing innovative plant-based food products [3, 4]. Plant-based foods and beverages qualify for vegan, vegetarian, and flexitarian diets and include a broad range of products mimicking animal-based foods (i.e., meat, dairy, eggs and seafood) [5, 6]. Vegan products are such foods that do not contain animal products, neither directly (meat, seafood, gelatin, lard, tallow, meat broth, and insects), nor indirectly from living animals or the processing of their products (milk, cheese, butter, eggs, or honey). On the other hand, vegetarian products might contain only the indirect products (lacto, ovo and ovo-lacto vegetarianism) but no direct products. Exceptions are pescatarians, who eat seafood but no meat, and pollotarians, who additionally eat poultry but no seafood or other types of meat.

In the realm of alternative plant-based products, meat analogues are particularly booming and rapidly moved from niche to more mainstream [7]. In 2021, the global

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meat alternatives' market accounted for $5.37 billion and is expected to reach $10.80 billion by 2028, exhibiting a compound annual growth rate (CAGR) of 10.48% [8]. Advances in texturization technologies and innovative ingredients are among the driving factors contributing into the design of alternative products that mimic the texture and taste of meat products [3].

Seafood alternatives or analogues are plant-based products designed with the objective to mimic the texture and organoleptic properties of seafood products. These products are gaining lot of attention for ethical and health reasons. The key drivers of the growth of this niche market are the rising awareness over overfishing, and the environmental impact of industrial fishery. North America is expected to dominate this market followed by Europe [9]. The main producers of these products are Amy's Kitchen (California, USA), Beyond Meat (California, USA), The Greenland LLC (Virginia, USA), Sotexpro (Bermericourt, France), Ingredion (Westchester, USA), Tofurky (Oregon, USA), Quorn Foods (Chicago, USA), Morningstar Farms (Ohio, USA), Gold and Green Foods (Uusimaa, Finland), Kerry Group (Naas, Ireland), and Cosucra Group (Pecq, Belgium) among others [9]. Seafood alternatives continue to expand offering various products such as tuna, calamari, fish fillet, fish fingers, fish sticks, caviar, and shrimps [10]. Ideally, these products are expected to provide equivalent intake of nutrients as in the conventional replaced products. "Real" seafood products are excellent sources of essential nutrients (vitamins A, B1, B2 and D) and minerals (iron, iodine, phosphorus, and zinc) among others [11]. They are further considered as the main sources of omega-3 (*n*-3) long-chain polyunsaturated fatty acids (LC-PUFA), eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids, that exert several body health benefits [12, 13]. Since seafood alternatives are mainly made from terrestrial plants that do not produce EPA and DHA, including pulses and cereals, these nutrients including vitamin B12 are expected to be low and insufficient to meet nutritional requirements [14–16]. Nevertheless, to our knowledge, the nutritional quality of commercial seafood alternatives has not been investigated to drive such conclusions. To address this information gap and to provide an informed purchase choice to the consumer, this work aimed to answer the question if the nutritional composition of seafood alternatives is nutritionally equivalent to that of conventional products. Thus, the mandatory nutritional composition (energy, total and saturated fatty acids, carbohydrates, sugars, proteins, and salt) included in the label of commercial seafood alternatives was analyzed and compared to conventional counterparts. In this study, all the commercial alternatives (i.e., tuna, shrimps, fish fingers, fish sticks, calamari, caviar, and salmon) launched in the global market from 2002 to 2021 were exhaustively considered.

Materials and methods

Data collection, extraction and database preparation

The search for seafood alternatives was carried out on December 2021, by consulting the Mintel Global New Product Database (Mintel GNPD-Mintel Group Ltd., London, UK, https://portal.mintel.com/portal/). The Mintel GNPD search was conducted using the criteria and keywords specified in Table 1. The first fish substitute was launched in the global market in 2002. Therefore, January 1st, 2002 until December 6th, 2021 was set as the time range to look for products launches. Out of the super-category of "foods",

Table 1 Search strategy used on Mintel Global New Product Database

Criteria	Vegan products	Vegetarian products	Conventional products
Sub-category	Meat substitutes	Meat substitutes	Fish products
Product name	Tuna Shrimps Calamari Fish fingers Fish sticks Salmon Fillet Caviar	Tuna Shrimps Calamari Fish fingers Fish sticks Salmon Fillet Caviar	Tuna Shrimps Calamari Fish fingers Fish sticks Salmon Fillet Caviar
Claim	Vegan/no animal ingredients	Exclude the claim vegan/no animal ingredients	No filter
Region	Global market		
Date	January 2002 to December 6th 2021		
Nutrition (from the label)	Energy (kcal/100 g); Fat (g/100 g); Saturated Fatty acids-SFA (g/100 g); Carbohydrates(g/100) g; Sugars (g/100 g); Protein (g/100 g); Salt (g/100 g)		

the search was focused on the category "Processed Fish, Meat, and Egg Products". For vegan products (containing no animal-based ingredients), fish alternatives (tuna, shrimps, calamari, fish fingers, fish sticks, salmon and fillet, and caviar) were retrieved from the subcategory "meat substitutes" specifying the claim "vegan/non animal ingredients" as a filter. For vegetarian products (containing one or more indirect animal-based ingredients, such as egg white or whey protein), the same parameters were used with the exclusion of the claim "vegan/non animal ingredients" from the list of the filters. The conventional products were retrieved from the sub-category "fish products", with the addition of filters depending on the product (tuna: cooked; shrimps: peeled and cooked; calamari: cooked rings; fish fingers: cooked; fish sticks: cooked; salmon: cooked; fillet: whole cooked). The complete mandatory nutritional information, in concordance with the EU Regulation 1169/2011 [17] and the *Codex Alimentarius* [18], was set as a filter for all the products. The results of all searches were exported to Microsoft Excel (Microsoft Office, Washington, WA, USA), hence allowing to create the database.

Data extraction

For all the selected products, the mandatory nutritional labelling, energy (kcal/100 g), total fat (g/100 g), saturated fatty acids-SFA (g/100 g), carbohydrates (g/100 g), sugars (g/100 g), proteins (g/100 g), and salt (g/100 g) were collected. Additionally, the most used claims and list of ingredients were also retrieved.

Statistical data analysis

The statistical analysis was carried out using the Statistical Package for Social Sciences software (IBM SPSS Statistics, Version 25.0, IBM corp., Chicago, IL, USA). Based on Kolmogorov–Smirnov test, the normality of data distribution was rejected, and therefore data were expressed as median values with interquartile ranges 25th–75th percentile. Differences in energy and nutrient contents per 100 g of products were analyzed using Mann–Whitney non-parametric test ($p < 0.05$).

Results

Number and types of products

A total of 149 seafood alternatives were launched from 2002 to 2021 (Table 2). In 2021, the number of overall alternative products has increased by 244% compared to 2002. Market launch shows several fluctuations before 2015 (Fig. 1). However, since 2014, launches of new products steadily increased (+ 550%).

Seafood alternatives were categorized into eight types namely tuna, shrimps, calamari, fish fingers, fish sticks, salmon, caviar, and fillet. Moreover, according to the claim vegan/ non-animal, products within each type were further grouped into vegan and vegetarian. Information about conventional products launched in the same period ($n = 973$) were also collected and compared. With regards to nutritional labeling, it seemed that not all products from the target categories showed the complete mandatory information set by the EU regulation 1169/2011 [17] and the *Codex Alimentarius* [18]. Based on Table 2, the results were as follows:

- Tuna alternatives ($n = 27$) can be classified into vegan products ($n = 14$) and vegetarian products ($n = 13$). The complete nutritional labeling was retrieved only for eight vegan and three vegetarian products. For comparison, conventional tuna products were collected, where only 17 products had complete labeling out of 24.

Table 2 Nutritional labelling of seafood products lunched in the global market

	All seafood alternatives		Vegan seafood alternatives		Vegetarian seafood alternatives		Conventional seafood products	
	All	With nutritional labeling*	All	With nutritional labeling*	All	With nutritional labeling*	All	With nutritional labeling*
Tuna	27	11	14	8	13	3	24	17
Shrimps	34	8	12	5	22	3	37	21
Calamari	4	4	3	3	1	1	140	24
Fish fingers	22	15	17	12	5	3	23	8
Fish sticks	16	16	13	13	3	3	20	8
Salmon	19	11	13	9	6	2	19	16
Caviar	23	15	1	1	22	14	692	26
Fillet	4	3	3	2	1	1	18	10

*Nutritional labeling: energy (kcal/100 g), total fat (g/100 g), saturated fatty acids—SFA (g/100 g), carbohydrates (g/100 g), sugars (g/100 g), protein (g/100 g), and salt (g/100 g)

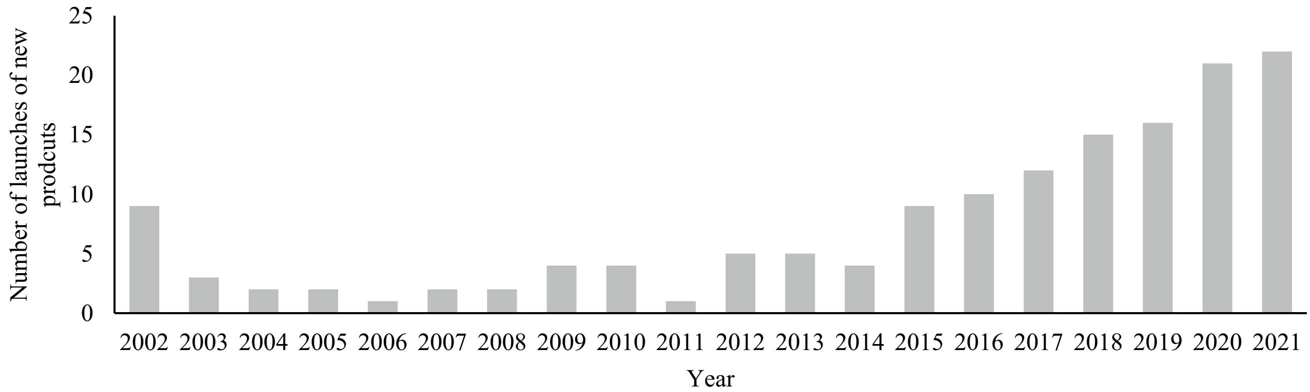

Fig. 1 Seafood substitutes' new products launches between 2002 and 2021 retrieved following the criteria and keywords stated in Table 1

- Total shrimps' alternatives were 34 products of which only 8 had a complete labeling that were classified into 5 vegan and 3 vegetarian products. For conventional shrimps' products, a total of 37 items were retrieved (only 21 with a complete nutritional information).
- Only 4 calamari alternatives were found, and they were classified into 3 vegan and one vegetarian, while 140 conventional calamari products were retrieved of which only 24 had a complete labeling.
- Out of a total of 22 fish fingers' alternatives, only 15 had a complete labeling of which 12 were vegan and 3 vegetarian products. Cooked fish fingers were in total 23 products, where 8 products had a complete mandatory labeling.
- All fish sticks' alternatives had complete labeling, and they were classified into 13 vegan and 3 vegetarian products.
- Out of 19 salmon alternatives, only 11 had a complete labeling and they were grouped into 9 vegan and 2 vegetarian products.
- Caviar alternatives were 23 products of which 15 had a complete labeling (one vegan and 14 vegetarian)
- Nutritionally labelled fillet alternatives ($n = 3$) were classified into two vegan and one vegetarian product.

Nutritional comparison

Overall seafood alternatives *versus* conventional products

As vegan/vegetarian consumers may directly substitute seafood products with plant-based alternatives, and consequently it is of high relevance to check if they are nutritionally equivalent. In Table 3, the median and interquartile range of the nutritional composition of alternatives and conventional products are reported. Table S1 summarized the main ingredients used in the formulations of all retrieved products.

Energy, total fat, SFA, carbohydrates and sugar contents in tuna alternative products are not significantly varying between alternative and the conventional ones. Notably, both product types had a relatively high fat content since they are canned in oil. Such products thus tend to have high calories and total fat. Protein content was found to be significantly higher in conventional products compared to the alternatives, while salt content was doubled in tuna alternatives compared to conventional products.

Shrimps' alternatives had similar energy, fat and SFA contents than conventional products, but significantly higher carbohydrate and sugar contents due to starchy ingredients used in their formulations (Table S1). The protein content in alternative products was much lower than in conventional products. Salt amounts in conventional shrimps were significantly higher than alternative products.

In calamari, no significant differences were found in terms of total fat, SFA, carbohydrates and sugars between alternative and conventional products. Although the median value of proteins (6.85 g/100 g) in conventional products was higher than the alternatives (1.09 g/100 g), no significant difference was observed in protein content due to the high range of variability in alternatives (0.25–33.63 g/100 g). Salt content was found to be significantly higher in conventional products.

For fish fingers, SFA, carbohydrates, sugars and protein contents were found similar between alternative and conventional products. However, alternative products had higher total fat, probably to mimic the structure of the conventional product. Alternatives had also the highest energy and salt contents.

Fish sticks' alternatives were found similar to conventional products for protein and sugar contents, but they had higher amounts of energy, total fat, SFA, carbohydrate and salt.

Alternative and conventional salmon products were not different in terms of carbohydrate, sugar, protein, and salt

Table 3 Median and interquartile range (25th–75th percentile) of nutritional composition of seafood alternatives vs conventional products launched in the global market

	N	Energy (kcal/100 g)	Total fat (g/100 g)	SFA (g/100 g)	Carbohydrate (g/100 g)	Sugars (g/100 g)	Protein (g/100 g)	Salt (g/100 g)
Tuna								
Alternatives	11	208 (100–216)	10.40 (2.50–15.40)	1.80 (0.00–2.60)	3.60 (3.51–7.00)	0.50 (0.10–2.30)	14.9 (12.9–14.9)	0.80 (0.45–1.90)
Conventional	17	179 (128–218)	10.00 (4.23–12.30)	1.70 (0.86–1.90)	0.50 (0.00–1.20)	0.00 (0.00–0.00)	25.3 (19.5–26.5)	0.39 (0.39–0.54)
Significance		ns	ns	ns	ns	ns	**	*
Shrimps								
Alternatives	8	96 (78–204)	3.70 (0.05–10.00)	0.01 (0.00–1.75)	10.6 (4.20–27.85)	1.50 (0.25–2.53)	1.00 (0.70–4.00)	0.34 (0.14–0.48)
Conventional	21	70 (63–78)	0.70 (0.30–1.00)	0.10 (0.00–0.30)	0.00 (0.00–0.55)	0.00 (0.00–0.10)	15 (14.50–17.00)	1.50 (1.33–2.05)
Significance		ns	ns	ns	***	*	***	***
Calamari								
Alternatives	4	202 (48–314)	4.26 (0.14–10.31)	0.64 (0.03–1.79)	11.88 (0.35–30.59)	0.99 (0.20–7.38)	1.09 (0.25–33.63)	0.49 (0.07–1.23)
Conventional	24	185 (115–203)	8.11 (3.98–9.95)	1.10 (0.89–1.20)	20.20 (11.10–24.00)	0.95 (0.28–2.15)	6.85 (6.08–10.98)	1.58 (1.10–1.85)
Significance		*	ns	ns	ns	ns	ns	***
Fish fingers								
Alternatives	15	233 (201–260)	11.20 (8.67–14.00)	1.10 (1.00–1.67)	20.00 (16.50–22.00)	0.89 (0.40–1.70)	11.33 (8.00–13.33)	1.20 (0.90–1.60)
Conventional	8	198 (187–221)	8.70 (6.85–10.37)	0.80 (0.63–0.96)	17.57 (16.13–18.8)	1.45 (0.86–3.15)	12.65 (11.17–13.53)	0.84 (0.58–0.98)
Significance		*	**	ns	ns	ns	ns	***
Fish sticks								
Alternatives	16	243 (221–249)	11.43 (9.30–13.71)	1.10 (0.97–1.26)	25.35 (13.23–26.00)	1.40 (1.10–1.55)	10.63 (7.95–12.90)	1.39 (1.19–1.60)
Conventional	8	190 (180–203)	8.12 (7.60–8.65)	0.85 (0.68–0.98)	15.50 (13.65–17.40)	0.92 (0.53–2.04)	11.92 (11.51–12.88)	0.88 (0.75–0.93)
Significance		***	*	*	*	ns	ns	*
Salmon								
Alternatives	11	144 (122–172)	7.07 (4.80–11.00)	0.93 (0.80–1.70)	8.60 (7.00–11.00)	0.60 (0.50–1.33)	2.77 (0.80–6.93)	1.20 (1.00–1.80)
Conventional	16	197 (154–218)	10.50 (8.88–13.00)	2.60 (1.68–3.63)	9.55 (1.70–14.98)	1.46 (0.67–1.68)	12.22 (9.58–14.65)	0.64 (0.59–0.96)
Significance		**	*	***	ns	ns	ns	ns
Caviar								
Alternatives	15	13 (12–15)	0.50 (0.20–1.60)	0.00 (0.00–0.10)	1.00 (0.00–1.00)	0.00 (0.00–0.00)	1.00 (0.10–1.00)	3.40 (0.00–3.50)
Conventional	26	125 (90–176)	4.75 (3.90–7.14)	1.00 (0.00–2.05)	2.00 (0.43–11.23)	0.75 (0.00–5.15)	11.00 (10.00–22.32)	4.00 (3.00–4.63)
Significance		***	***	ns	*	*	***	*
Fillet								
Alternatives	3	209 (193-nd)	8.90 (3.20-nd)	1.10 (0.30-nd)	15.40 (8.50-nd)	0.80 (0.50-nd)	13.40 (11.00-nd)	1.38 (0.72-nd)
Conventional	10	200 (173–213)	13.00 (8.70–13.00)	2.20 (0.80–2.50)	0.50 (0.00–16.25)	0.10 (0.00–0.90)	20.00 (13.00–20.00)	0.60 (0.10–1.77)
Significance		ns	ns	ns	ns	ns	*	ns

Values are expressed as median (25th–75th percentile)

nd not determined, *N* number of items

*$p<0.05$, **$p<0.01$, ***$p<0.001$, *ns* non-significant ($p>0.05$)

contents, however, the alternative products had lower energy, total fat and SFA contents.

Caviar alternatives had significantly lower energy, total fat, carbohydrate, sugar, protein and salt contents than the conventional products. SFA content was found similar between both groups.

Alternative and conventional fillet products had similar energy, total fat, SFA, carbohydrates and sugars contents. Nevertheless, conventional products contained more proteins and less salt than the alternative counterparts.

Vegan versus vegetarian seafood alternatives

For a better understanding of the nutritional profile of alternative seafood products, each product type was further analyzed by comparing the corresponding vegan and vegetarian categories. Table 4 outlines the median and quartiles of the mandatory nutritional information for vegan and vegetarian products.

For tuna, median values of energy, fat, sugar, SFA, protein and salt contents were found comparable in vegan and vegetarian products, however, carbohydrates were significantly higher in vegetarian than in vegan products.

The nutritional profiles of vegetarian and vegan shrimps were comparable in this database that can be due to the high intra-variability of the products.

Vegan fish fingers had higher energy, fat and salt contents but no significant differences in SFA, carbohydrate, sugar, and protein contents compared to vegetarian products.

No significant differences were found for the target nutrients between vegan and vegetarian fish sticks' products.

For calamari, salmon, caviar and fillet products, no statistical comparison was possible due to the few items available. Vegetarian calamari alternatives consisted of only one product which was characterized by high energy, protein, and carbohydrate contents. Vegetarian salmon showed higher energy and protein contents compared to vegan. Both vegan and vegetarian products had similar fat and SFA contents. Vegan and vegetarian caviar had similar low energy and sugar contents, and no SFA. Vegan fillet showed the highest carbohydrates and salt contents.

Main claims on the packaging of seafood alternatives

Table 5 summarizes the most used claims on alternative products. The top claims were vegan, vegetarian, and plant-based. Claims declaring low/no/reduced allergens were mentioned in 20% of the alternative products, along with 13% of total products claiming to be gluten-free. Regarding nutritional claims, 15% ($N=22$) of all products were claimed 'high/added protein'. Around 4% of the alternative products were fortified with some vitamins (i.e., vitamin B12) and minerals (i.e., iron). Claims declaring the absence of genetically modified organisms (GMO) ingredients were found in 11% of all products. Ensuring the naturalness of alternative products was through using the claim "no additives/preservatives" in 11% of total products. As for sustainability related claims, 4% of all products were declared organic.

Discussion

Although the first launches of seafood alternatives go back to 2002, a steady increase started since 2014, and, the number of launches increased by 5.5 times from 2014 to 2021. This can be partly due to the boom of plant-based alternatives in the recent years, mainly for environmental and ethical concerns [3]. Consumers following strict vegan and vegetarian diets remain a small group of the population, anyway, flexitarians, restricting animal-based foods, accounted for over 40% of global consumers in 2020 [19]. The demand for plant-based food has further accelerated during the COVID-19 pandemic due to changes in food habits of certain consumers. Consumers are more aware about the relatedness between nutrition and health [20]. For now, meat alternatives are the largest plant-based market, but it is expected that other categories including seafood alternatives will grow fast in the upcoming years.

A well-planned vegan diet was proposed to have a healthy impact by reducing blood pressure [21] and the risk towards cardiovascular disease, diabetes, cancer, chronic disease [22, 23]. Nevertheless, the fast growth in plant-based alternatives across many categories (meat, egg, dairy and seafood) might rise some doubts about their nutritional properties and the so-called health benefits. The 'health halo' effect of several plant-based alternatives (e.g., meat, dairy milks, yogurt and processed cheese) was not found entirely justifiable after evaluating and comparing their nutritional profiles with those of the corresponding conventional foodstuffs [24–27].

This paper focuses, for the first time, on seafood alternatives sold in the global market to point out their advantages and limitations from a nutritional perspective. Nevertheless, this study was limited by the mandatory nutritional information reported on the label of the products (which in many products was incomplete). As a consequence, it was also impossible to evaluate potential nutritional limitations of the alternative products in terms of micronutrients usually associated to the consumption of conventional seafoods (e.g., vitamins, minerals and essential fatty acids as EPA and DHA). Another limitation of the present study was the scarce number of items available for some types of seafood alternatives, such as caviar and calamari, which prevented a robust comparison with the corresponding conventional categories.

Table 4 Median and interquartile range (25th–75th percentile) of nutritional composition of vegan and vegetarian seafood alternatives sold in the global market

	N	Energy (kcal/100 g)	Total fat (g/100 g)	SFA (g/100 g)	Carbohydrates (g/100 g)	Sugars (g/100 g)	Protein (g/100 g)	Salt (g/100 g)
Tuna								
Vegan	8	216 (107–216)	15.40 (3.55–15.40)	2.54 (0.28–2.60)	3.60 (2.48–4.65)	1.65 (0.10–2.30)	14.90 (14.00–14.90)	1.40 (0.52–1.90)
Vegetarian	3	176 (70-nd)	6.20 (0.00-nd)	1.00 (0.00-nd)	10.48 (3.51-nd)	0.14 (0.00-nd)	12.28 (6.60-nd)	0.55 (0.30-nd)
Significance		ns	ns	ns	*	ns	ns	ns
Shrimps								
Vegan	5	94 (79–240)	2.50 (0.10–11.00)	0.00 (0.00–2.00)	18.40 (7.10–31.00)	2.00 (1.00–13.35)	4.00 (0.30–6.15)	0.40 (0.27–0.47)
Vegetarian	3	98 (30-nd)	4.90 (0.00-nd)	0.01 (0.00-nd)	6.00 (3.60-nd)	1.00 (0.00-nd)	1.00 (-nd)	0.10 (0.00-nd)
Significance		ns	ns	ns	ns	ns	ns	ns
Calamari								
Vegan	3	164 (9-nd)	8.24 (0.10-nd)	1.18 (0.00-nd)	1.40 (0.00-nd)	0.80 (0.00-nd)	1.00 (0.00-nd)	0.71 (0.27-nd)
Vegetarian	1	338.89	0.28	0.11	33.33	9.44	44.44	0
Significance		–	–	–	–	–	–	–
Fish fingers								
Vegan	12	235 (212–260)	11.75 (9.40–14.21)	1.15 (1.00–1.58)	19.80 (16.71–22.94)	0.81 (0.43–1.63)	12.17 (8.06–13.33)	1.47 (1.11–1.68)
Vegetarian	3	201 (77-nd)	5.00 (0.00-nd)	0.00 (0.00-nd)	21.02 (16.00-nd)	1.00 (0.00-nd)	10.00 (0.67-nd)	0.61 (0.48-nd)
Significance		*	**	ns	ns	ns	ns	***
Fish sticks								
Vegan	13	242 (218–251)	9.30 (9.30–13.16)	1.10 (0.93–1.11)	25.70 (17.95–26.21)	1.40 (1.11–1.50)	10.53 (7.86–12.8)	1.36 (1.00–1.59)
Vegetarian	3	245 (232-nd)	15.00 (10.00-nd)	1.32 (1.10-nd)	12.00 (11.42-nd)	0.80 (0.79-nd)	10.68 (10.58-nd)	1.50 (1.37-nd)
Significance		ns	ns	ns	ns	ns	ns	ns
Salmon								
Vegan	9	131 (104–144)	7.07 (4.60–11.00)	0.90 (0.80–1.70)	8.60 (6.05–9.80)	0.80 (0.50–1.57)	2.70 (0.65–6.05)	1.20 (1.02–1.80)
Vegetarian	2	185 (182-nd)	7.35 (6.60-nd)	1.10 (1.00-nd)	16.15 (10.3-nd)	0.30(0-nd)	12.75 (7-nd)	0.98 (0.75-nd)
Significance		–	–	–	–	–	–	–
Caviar								
Vegan	1	15.00	1.60	0.00	0.00	0.0	0.10	0.30
Vegetarian	14	13 (12–15)	0.50 (0.20–1.15)	0.00 (0.00–0.10)	1.01 (0.23–1.05)	0.0 (0.0–0.0)	1.00 (0.08–1.1)	3.45 (0.00–3.50)
Significance		–	–	–	–	–	–	–
Fillet								
Vegan	2	237 (193-nd)	12.10 (3.20-nd)	1.10 (0.30-nd)	18.75 (8.50-nd)	0.80 (0.50-nd)	12.20 (11-nd)	1.49 (1.38-nd)
Vegetarian	1	209	8.90	1.10	15.40	0.80	14.3	0.72
Significance		–	–	–	–	–	–	–

Values are expressed as median (25th–75th percentile)

"–" not calculate, *ND* not determined, *N* number of items

*$p<0.05$, **$p<0.01$, ***$p<0.001$, *ns* non-significant ($p>0.05$)

Table 5 Top ten claims on the packaging of alternative seafood products

Claims	Tuna	Shrimps	Calamari	Fish fingers	Fish sticks	Salmon	Caviar	Fillet	Total of products
Vegan/no animal	52% (*n* = 14)	15% (*n* = 5)	75% (*n* = 3)	68% (*n* = 15)	81% (*n* = 13)	58% (*n* = 11)	4% (*n* = 1)	50% (*n* = 2)	43% (*n* = 64)
Gluten-free	44% (*n* = 12)	3% (*n* = 1)	25% (*n* = 1)	0% (*n* = 0)	0% (*n* = 0)	32% (*n* = 6)	0% (*n* = 0)	0% (*n* = 0)	13% (*n* = 20)
Vegetarian	44% (*n* = 12)	9% (*n* = 3)	25% (*n* = 1)	55% (*n* = 12)	69% (*n* = 11)	16% (*n* = 3)	61% (*n* = 14)	50% (*n* = 2)	39% (*n* = 58)
Low/no/reduced allergen	44% (*n* = 12)	3% (*n* = 1)	25% (*n* = 1)	23% (*n* = 5)	31% (*n* = 5)	32% (*n* = 6)	0% (*n* = 0)	0% (*n* = 0)	20% (*n* = 30)
High/added protein	33% (*n* = 9)	3% (*n* = 1)	0% (*n* = 0)	18% (*n* = 4)	38% (*n* = 6)	0% (*n* = 0)	0% (*n* = 0)	50% (*n* = 2)	15% (*n* = 22)
GMO-free	30% (*n* = 8)	6% (*n* = 2)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	37% (*n* = 7)	0% (*n* = 0)	0% (*n* = 0)	11% (*n* = 17)
Plant-based	30% (*n* = 8)	6% (*n* = 2)	0% (*n* = 0)	27% (*n* = 6)	38% (*n* = 6)	26% (*n* = 5)	4% (*n* = 1)	75% (*n* = 3)	21% (*n* = 31)
Organic	19% (*n* = 5)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	3% (*n* = 5)
Vitamins/minerals fortified	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	38% (*n* = 6)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	4% (*n* = 6)
No additives/preservatives	19% (*n* = 5)	0% (*n* = 0)	0% (*n* = 0)	55% (*n* = 12)	0% (*n* =)	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	11% (*n* = 17)

n number of items

Even considering these limitations, this study highlighted the high variability of the nutritional profile among seafood alternatives (in terms of categories and vegan/vegetarian classification) due to the absence of established standards. Most of the seafood alternatives showed lower protein content if compared to the corresponding conventional seafood products, while some of them had higher calories and fats (finger and sticks) or contain more salt (tuna, fingers, sticks, salmon, fillet). These results are comparable to those found for plant-based dairy or meat alternatives [25, 26]. Milk, cheese or yogurt alternatives made from plant-based ingredients, mainly cereals, nuts and pulses, were found not nutritionally equivalent to cow's milk, showing limitations in protein content/quality, while containing higher levels of carbohydrates and sugars [26]. Similarly, lower protein content and higher amount of salt characterized the commercially available meat alternatives (i.e., burgers and ground meat) if compared to conventional products [25, 28]. Additionally, plant proteins, generally used to produce the seafood alternatives do not provide the same protein quality (in terms of amino acids profile and bioavailability) of the animal proteins [3]. Indeed, it is well known that plant proteins lack specific essential amino acids compared to animal proteins [29] and are less digestible than animal proteins due to their globular structure limiting the accessibility of digestive enzymes [30]. These are serious limiting factors that need to be addressed to improve the nutritional quality of seafood alternatives. Possible solutions should include the incorporation of blends of protein isolates or concentrates (from cereals, pulses or seeds) to increase protein content and quality without increasing carbohydrates content (like flours). For instance, a blend of wheat protein and pea protein isolates can enable a complete essential amino acid profile. Furthermore, alternative protein sources such as seaweed, microalgae and mycoprotein can be added to increase protein content among other health-beneficial compounds. Besides biofortification, adding vitamins and minerals can be a valid strategy to mimic the composition of "real" seafoods and thus offering consumers' parity in terms of texture, taste and nutrition.

Specific regulations and labeling rules, providing a clearer and more complete information to the consumer about the protein quality and bioavailability, should also be implemented.

On the other hand, 11% of the products analyzed in this study do not include additives and preservatives in their formulations. It was reported that both flexitarians and meat lovers have a preference towards alternative products that did not contain additives [31]. The use of clean label ingredients is moving upward cross the food and beverages sectors leading consumers to carefully consider the ingredients used in foods [32]. This trend has emerged due to the concern of consumers about healthiness and sustainability of food products. In a survey conducted in Spain, flexitarians and meat-eaters associated clean label to plant-based, and thus for them plant-based products are perceived as natural and familiar [31]. Similarly, vegetarian and flexitarians attitudes were reported to be more related to natural plant-based foods made with natural ingredients [33].

Furthermore, product labels were the most common source of sustainability information [34]. Thus, organic claim (used in 4% of the products included in this study) is a way to contribute in vegan and vegetarian consumers' perception of the foods as environmentally friendly and sustainable [35]. Several studies have shown that consumers, not only vegan/vegetarian, who have a strong preference for organic food tend to reduce meat consumption and increase plant-based foods [36–38]. It was also reported that local origin, organic labeling and reduced CO_2 were important factors in their product decision process [39].

Conclusion

The present study showed that a selection of commercial seafood alternatives can be interesting from a nutritional point of view due to their fatty acids profile (tuna, shrimps, calamari, fish fingers, salmon, caviar and fillet), reduced salt content (shrimps, calamari and caviar), or protein content (calamari, fingers sticks and fingers, and salmon). Nevertheless, seafood alternatives launched in the market between 2002 and 2021 showed extremely variable nutritional profiles, and, in many cases, a substantial lack of nutritional equivalence with the corresponding conventional products (lower protein contents, higher calories, higher fats and salt contents).

Thus, the nutritional advantages of the present seafood alternatives as a part of a healthy diet are still unclear and more work is required to improve their nutritional profile in terms of macro- and micro-components, by developing a new generation of reformulated products, and to provide a more complete nutritional information to consumer.

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Declarations

Conflict of interest The authors declare no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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