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Meat substitutes - past, present, and future of products available in Brazil: changes in the nutritional profile

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A R T I C L E I N F O

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A B S T R A C T

Plant-based meat substitutes are products used to replace meat in the human diet. These products have developed from traditional whole-grain meat substitutes to products based on an advanced technology called 2nd generation meat substitutes. Increased market visibility of 2nd generation products raised questions about the products´ healthiness once they are classified by NOVA as ultra-processed, are allegedly high in salt and saturated fat, and might not be nutritionally equivalent to meat. To answer those queries, we evaluated the nutritional profile of the 3 generations of products available in the Brazilian market. Products were classified into one of three stages of technology as traditional meat substitutes, 1st generation meat substitutes, or 2nd generation meat substitutes. Their nutritional values, ingredient composition, and nutrient profile were analyzed and compared. Most of the products analyzed (169 in total) were classified as 1st generation meat substitutes (55.6%), while 2nd generation ones represented 16% of products. The 2nd generation of meat substitutes presented a higher amount of protein, sodium, saturated fat, and a greater number of additives than previous generation products. The future generation of meat substitutes should focus on reducing saturated fat content and the use of fewer additives.

1. Introduction

Plant-based meat substitutes are products used to replace meat in the human diet and mimic the texture, taste, and appearance of meat products (Tziva et al., 2020). The meat substitutes marketplace is expanding rapidly around the globe, going beyond the vegetarian market to include meat-loving consumers who want to reduce their meat consumption because of health, ethical, cost and sustainability concerns (Dagevos and Voordouw, 2013). Meat substitutes are also options for convenience-oriented consumers that want to reduce meat intake but not at the expense of flavor and convenience (Wild, 2016).

Much has been said about meat substitutes: healthy, unhealthy (Kyriakopoulou et al., 2018), ultra-processed, the protein promise of the future (Ismail et al., 2020). Some people say it is fake food (Ancestral Nutrition, 2017), others promise salvation of the planet (Van der Weele et al., 2019) or burger absolution as healthy food (Lichstein, 2020). Despite the recent furor around it, meat substitutes are not a new food category as such (Bohrer, 2019). In western countries, foods from ancient production such as tofu and tempeh became available by the 1960s (Wild, 2016) when the hippie movement incorporated oriental influences in western food culture (Rödl, 2019). In Brazil, the hippie movement disseminated vegetarianism and a natural lifestyle. Food practices promoted by them included vegetarian meat substitutes such as burgers and patties made with lentils, beans, mushrooms, and fresh ingredients (Lifschitz, 1997; Sigolo, 2020). These early products, made by whole ingredients, can be called traditional meat substitutes (Lichstein, 2020), despite having a proposal to replace meat, their consumption remained restricted to the vegetarian public. Due to the long-lasting effect of natural lifestyle on Brazilian food culture, these traditional meat substitutes are still commercialized (Lifschitz, 1997; Sigolo, 2020).

Advancement in the production of meat substitutes happened with the launching of dry textured vegetable protein (TVP), which emerged by the mid to late 20th century (Ismail et al., 2020). Initially perceived as meat extenders, TVP gradually started being used as a meat substitute (He et al., 2020), giving rise to 1st generation meat substitutes (Tziva et al., 2020). Manufactured by low moisture cooking extrusion of defatted soy meal, soy protein concentrate, or gluten, the products obtained had a fibrous and spongy texture. However, the market share remained very small and restricted to vegetarians for a long time (Tziva et al., 2020).

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As the demand for meat-free products increased, due to the rising concern of the environmental impact of meat production (He et al., 2020), and the expansion of the market by flexitarian consumers seeking a varied and healthy diet (Curtain and Grafenauer, 2019), producers developed meat substitutes more similar to meat. Based on technologies such as high moisture cooking extrusion, the 2nd generation meat substitutes aim to imitate the taste and experience of eating meat (Dekkers et al., 2018), delivering products of appearance, nutritional facts, aroma, and taste very similar to authentic meat products (He et al., 2020), such as whole cut meat and chicken strips with visible structured protein fibers. Also called the new generation of meat analogues (He et al, 2020) or novel meat analogues (Ismail et al, 2020), the 2nd generation of meat substitutes are marketed to a broader consumer base such as flexitarians and omnivorous (Lichstein, 2020). To achieve this, novel ingredients or innovative processes were developed (Ismail et al., 2020). In Brazil, 2nd generation meat substitutes started being commercialized in 2019 by a foodtech startup, soon other five companies followed, upgrading their portfolio or initiating a new business (GFI, 2020).

Increased visibility of meat substitutes was followed by media and academic repercussions (Boukid, 2021). The ultra-processed nature of 2nd generation meat substitutes, made with refined ingredients, generates a lot of debate whether they can be considered as a healthy choice or not (Santo et al., 2020). Some health professionals have been concerned whether these products can fully replace meat and at what cost for people´s health (Hu et al., 2019), once they are allegedly rich in saturated fat and sodium (Bohrer, 2019). At the same time, there is a healthy halo around plant-based products, with consumers associating plant-based to healthy eating, independent of the nutritional composition (Besson et al., 2020). As a result of such conjecture, it is relevant to evaluate, compare and make a critical note regarding the nutritional composition and the processing nature of the ingredients in these products.

Method

Search for meat substitutes products

To determine the composition of meat substitutes available on the Brazilian market, we searched for products on the company's websites, and at local stores (supermarkets and health food stores in the city of Rio de Janeiro). We analyzed information obtained from the product's labels or the ones included on the company's website. This search was conducted from September to November of 2020.

To search for meat substitutes we considered the following criteria: the products must be plant-based, precooked, and resemble meat, chicken, fish, or processed meat. Products, such as tofu, tempeh, and legumes, consumed traditionally as part of a vegetarian diet, not primarily designed to replace meat (He et al., 2020), were excluded in the search. Besides, products without available nutrition facts label were not included in our research.

Classification of products: stage of technology development

Products were classified into one of three stages of technology development as follows: Traditional meat substitutes- made exclusively with fresh or minimally processed ingredients and whole grain legumes, such as lentils burgers and chickpea sausages, 1st generation meat substitutes- produced mainly with TVP (by low moisture cooking extrusion, and/or gluten), are targeted to the vegetarian market, and have been in the market since 1990´s (Tziva et al., 2020), such as soy chunks and burguers made of TVP; 2nd generation meat substitutes - Based on high moisture cooking extrusion to produce new products of which the appearance, protein content, aroma, and taste are very similar to authentic meat products, such as chicken strips, salmon filet and bacon. Commonly, these products have a nationwide distribution (He et al., 2020), and

Table 1
Classification criteria for meat substitutes products.

	Technology	Ingredients	Public
Traditionalmeat substitutes	Homemade style	Fresh or minimally processed ingredients, like pulses and vegetables	Vegetarian public
1st Generation meat substitutes	Low moisture cooking extrusion	Meal, soy protein concentrate or wheat gluten	Vegetarian public
2nd Generation meat substitutes	High moisture cooking extrusionfermentation	Novel protein sourcesPlant protein isolate and plant protein concentrate	Flexitarians and general public

have been in the Brazilian market since 2019 and being produced by six manufacturers (GFI, 2020); Additionally, products were divided into six categories such as meat products, chicken products, fish products, burgers, ground beef, and processed meat. The criteria for classification of the products can be seen on **Table 1**.

Nutrient composition and ingredient analysis

The information contained in the nutrition facts labels were transcribed and analyzed. The amounts of all nutrients (carbohydrate, protein, total fat, saturated fat, fibers, iron, vitamin B_{12}, zinc, and sodium) and total energy (kcal) presented in each product were calculated for 100 g to allow comparison between products. The list of ingredients for each product was transcribed and each ingredient was allocated according to the main nutrient it provides (protein, carbohydrate, fat), natural seasonings, and additives.

Nutrient Profile

To analyze how the products perform according to their nutritional quality, Brazilian Regulations RDC nº 429 (Brasil 2020a) and IN nº 75 (Brasil 2020b) were applied. These legislations define criteria for front of package labeling of nutrients that should be avoided and nutritional claims for nutrients whose consumption should be encouraged. The summary of the criteria applied is shown in **Table 2**. Additionally, we evaluated if the serving size stated on the nutrition facts label was adequate according to RDC nº 360 (Brasil, 2003). The calorie density of the products was calculated according to the RDC nº 360 (Brasil, 2003), dividing 150 kcal per 80 g of serving size. Products within an interval of minimum (-20% of calorie density) and maximum (+20% calorie density) were classified as containing adequate calorie density.

Statistical analysis

Results of nutritional composition were expressed as median, minimum, and maximum. Products grouped by stage of technology development were compared by non-parametric Kruskal Wallis test, followed by Dunn post hoc test with Bonferroni adjustment. The level of statistical significance was set at $p < 0.05$. Analysis was made at RStudio Desktop version 1.4.1106.

Results

Product description

We found 180 meat substitute products in the Brazilian market produced by 27 different manufacturers. However, we only obtained data of 169 products due to a lack of available label information online. Products divided by the stage of technology development and product type can be seen in **Table 3**. Most of the products analyzed were considered 1st generation meat substitutes (55.6%), while 2nd generation ones represented the lowest share of products available on the market (16%), produced by only 6 manufacturers. The most common products among the 2nd generation were burgers and chicken (37% each).

Nutritional composition

The median value of total energy was 181 kcal/100 g product, with minimum and maximum values of 34 kcal and 343 kcal/100 g product, respectively (**Table 4**). The 1st generation products had the highest median value of 192 kcal/100g product. A great range from minimum to maximum energy values was seen in the three product categories (58.6 to 343 kcal for traditional; 34 to 325 for 1st generation and 108 to 326 for 2nd generation). Serving size was significantly different between traditional products to 1st generation and 2nd generation products, however a greater variability was noticed within groups than between the different groups.

Table 2
Nutrition claims and cutoff points used to classify meat substitutes products according to the Brazilian food legislation (RDC n° 429 and IN n° 75).

Nutrients	Specificity of nutritional claims
Protein	(Also needs to attend to minimum amino acids composition stated at IN nº 75). Source: 5g per serving size (6.25 g per 100 g). High Content: minimum of 10 g protein per serving size (12.5 g per 100 g).
Total fat	**Zero Content:** Maximum of 0.5g per serving size (0.62 g of fat per 100 g) and all fat fractions must be equal to zero on the nutrition facts label. Additionally, no fat source ingredients must be present in the ingredients list. **Low:** Maximum 3g of fat per serving size (3.75 g per 100g).
Saturated fat	**High:** Above 6 g per 100g
Fiber	**Source:** must contain at least 2.5 g of fiber per serving size (3.13 g per 100 g) **Rich:** must contain at least 5 g of fiber per serving size (6.25 g per 100 g)
Sodium	**Zero Content:** Maximum of 5 mg per serving size (6.25 mg per 100 g) **Very Low:** Maximum of 40 mg per serving size (50 mg per 100 g). **Low:** Maximum of 80 mg per serving size (100 mg per 100 g). **No claims allowed:** Above 100 mg. **High:** Above 600 mg per 100g
Iron, vitamin B_{12}, zinc	**Source** of vitamins or minerals: at least 15% of the daily recommended dietary intake must be provided by serving size. **Rich** in vitamins or minerals: at least 30% of the daily recommended dietary intake must be provided by serving size.

Table 3
Product type categorized by stages of technology development.

	Traditional (N=48; 28.4%)	1st Generation (N=94; 55.6%)	2nd Generation (N=27; 16.0%)
Burger	29 (60.4%)	18 (19.1%)	10 (37.0%)
Chicken	1 (2.1%)	9 (9.6%)	10 (37%)
Fish	0 (0%)	7 (7.4%)	2 (7.4%)
Ground beef dishes	13 (27.1%)	14 (14.9%)	2 (7.4%)
Meat	2 (4.2%)	17 (18.1%)	1 (3.7%)
Processed Meat	3 (6.2%)	29 (30.9%)	2 (7.4%)

For detailed explanation of categories check details on **Table 1**.

Table 4
Nutritional composition of meat substitutes per 100g of the product, categorized according to the stage of technology development.

	Traditional N=48 (28.4%)	1st Generation N=94 (55.6%)	2nd Generation N=27 (16.0%)
Serving Size (g)			
Median[min and max]	100[20, 270] a,	50[20, 150] b	80[30, 130] b
Energy (Kcal)			
Median[min and max]	159[58.6, 343] a	192[34, 325] b	175[108, 326] a, b
Carbohydrate(g)			
Median[min and max]	23.5[8.49, 66.3] a	14.8[0, 51.7] b	9.67[2.40, 23.9] b, c
Protein (g)			
Median[min and max]	5.09[1, 60.3] a	13.6[1.83, 32.4] b	13.8[7, 23] b
Total fat (g)			
Median[min and max]	2.66[0, 9.25] a	6.17[0, 40.0] b	9.23[0, 21.5] b
Saturated fat (g)			
Median[min and max]	0.4[0, 3.58] a	0.95[0, 5.32] b	3.75[0, 12.3] c
Fiber (g)			
Median[min and max]	4.4[0, 9.36] a	4.57[0, 20] a	4.3[0.4, 6.25] a
Sodium (mg)			
Median[min and max]	343[15, 1540] a	575[18.0, 1580] b	478[326, 700] b
Iron (mg)			
Median[min and max]	2.7[2.7, 2.7] a	1.34[0.42, 5] a	3.5[1.62, 11.7] a
Zero content	47 (97.9%)	88 (93.6%)	8 (29.6%)
Vitamin B_{12} (µg)			
Median[min and max]	NA[NA, NA] a	0.86[0.06, 1.67] a	0.90[0.30, 2] a
Zero content	48 (100%)	92 (97.9%)	10 (37.0%)
Zinc (mg)			
Median[min and max]	NA[NA, NA] a	2[2, 2] a	1.75[1.38, 2.10] a
Zero content	48 (100%)	93 (98.9%)	22 (81.5%)

Results are shown as median [minimum and maximum]. Different letters in the same row show significant difference among the groups at $p < 0.05$. For detailed explanation of categories check details on **Table 1**.

The 1st and 2nd generation meat substitutes had similar protein content (13.6 g/100 g and 13.8 g/100 g respectively), while traditional meat substitutes had a median of 5.09 g/100 g. We noticed a variation in the protein content within the same product category. The minimum and maximum protein content of all products were 1 g protein/100 g product and 60.3 g protein/100 g dry product, respectively.

We also noticed the variation in the carbohydrate content within the same level of technology ranging from 8.49 g/100 g to 66.3 g/100 g for traditional meat substitutes and from 2.40 g/100 g to 23.9 g/100 g for 2nd generation meat substitutes. The median value of dietary fiber ranged from 3.9 to 5.5 g/100 g in all categories and didn´t vary significantly among categories. However, the three categories had products with zero fiber content.

Among the micronutrients, none of the traditional meat substitutes had any amount of iron, vitamin B_{12}, and zinc reported on the nutrition facts label, except for one product that reported 2.7 mg/100 g of iron, as can be seen in **Table 4**. The 1stgeneration meat substitutes had 6 products (12%) containing iron, 2 products (2.1%) containing vitamin B_{12}, and one product (1.1%) containing zinc. The 2ndgeneration meat substitutes had 19 products (70.4%) containing iron, 17 products (63%) with vitamin B_{12}, and 5 products (18.5%) with zinc. The sodium content varied greatly among products. The highest median (575 mg/100 g product) and intra-variation within category (18 mg/100 g product to 1580 mg/100 g product) was found for 1stgeneration meat substitutes.

Nutrient profile

In **Table 5** we showed product´s adequacy to Brazilian food legislation according to serving size and calorie density RDC nº 360 (Brasil, 2003) and nutrient profile according to RDC nº 429 (Brasil 2020a) and IN nº 75 (Brasil 2020b). Overall, 61.5% (n = 104) of the products were adequate in calorie density and 11.8% (n = 20) were below. High-calorie density was noticed in 4.2% (n=2) of traditional products, 16% (n=15) of 1st generation meat substitutes, and 11.1% (n=3) of 2nd generation meat substitutes. Across all products, 45.5% (n=77) were considered as high content of protein and 31.9% (n=54) as source of protein. All 2nd generation meat substitutes could claim that the products were either source (n=7, 25.9%) or rich (n=20, 74.1%) in protein. Regarding total fat, 11.8% (20) of the products could claim zero content of fat. Low-fat claims were eligible by 18.3% (31) of the overall products, from that 70.9% (22) were traditional products. Overall, we found that products made in traditional style had a lower amount of fat than 2nd generation products. From our results, 77.8% of the 2nd generation products were eligible to make dietary fiber claims as source (74.1%) or as rich in fiber (3.7%). Sodium content was considered high for 6 products of the 1st generation and one traditional product, 2nd generation products amount of sodium was considered adequate. Saturated fat was high in 77.8% of the 2nd generation products, but not on the previous generation products. (**Table 5**).

Table 5
Adequacy of nutrients per 100g of the product in each stage of technology development according to the Brazilian food legislation (RDC n° 429 and IN n° 75).

	Traditional N=48 (28.4%)	1st Generation N=94 (55.6%)	2nd Generation N=27 (16.0%)
Serving Size			
Low	11 (22.9%)	53 (56.4%)	3 (11.1%)
Adequate	23 (47.9%)	37 (39.4%)	17 (63.0%)
High	14 (29.2%)	4 (4.3%)	7 (25.9%)
Calorie Density			
Low	16 (33.3%)	22 (23.4%)	7 (25.9%)
Adequate	30 (62.5%)	57 (60.6%)	17 (63.0%)
High	2 (4.2%)	15 (16.0%)	3 (11.1%)
Protein			
High Content	5 (10.4%)	52 (55.3%)	20 (74.1%)
Source	15 (31.1%)	32 (34%)	7 (25.9%)
No claims allowed	28 (58.3%)	10 (10.6%)	0
Total fat			
Low	22 (45.8%)	9 (9.6%)	0 (0%)
Zero Content	5 (10.4%)	13 (13.8%)	2 (7.4%)
No claims allowed	21 (43.8%)	72 (76.6%)	25 (92.6%)
Saturated Fat			
Adequate	48 (100%)	94 (100%)	6 (22.2%)
High	0	0	21 (77.8%)
Fiber			
Source	24 (50%)	46 (48.9%)	20 (74.1%)
Rich	11 (22.9%)	26 (27.7%)	1 (3.7%)
No claims allowed	13 (27.1%)	22 (23.4%)	6 (22.2%)
Sodium			
Low	5 (10.4%)	0 (0%)	0 (0%)
Very Low	2 (4.2%)	3 (3.2%)	0 (0%)
No claims allowedHigh	40 (83.3%)1 (2.1%)	85 (90.4%)6 (6.4%)	27 (100%)0
Iron			
Source	1 (2.1%)	1 (1.1%)	11 (40.7%)
Rich	0 (0%)	1 (1.1%)	6 (22.2%)
No claims allowed	0 (0%)	4 (4.3%)	2 (7.4%)
Zero content	47 (97.9%)	88 (93.6%)	8 (29.6%)
B12			
Source	0 (0%)	0 (0%)	4 (14.8%)
Rich	0 (0%)	1 (1.1%)	12 (44.4%)
No claims allowed	0 (0%)	1 (1.1%)	1 (3.7%)
Zero content	48 (100%)	92 (97.9%)	10 (37.0%)
Zinc			
Source	0 (0%)	1 (1.1%)	4 (14.8%)
Rich	0 (0%)	0 (0%)	1 (3.7%)
Zero content	48 (100%)	93 (98.9%)	22 (81.5%)

For detailed explanation of categories check details on Table 1 Nutrition claims and cutoff points used to classify meat substitutes products according to the Brazilian food legislation (RDC n° 429 and IN n° 75) are show on Table 2.

Source for proteinaceous ingredients

Fig. 1 shows that soy protein was the most common protein ingredient (41%) in a variety of forms, such as soy extract, concentrated soy protein, hydrolyzed soy protein, and isolated soy protein. Gluten was the second most common protein ingredient (19%). Pulses (whole grain and flour) such as chickpeas, lentils, black-eyed beans, black beans, and white beans were present in 13% of the products. Ingredients derived from peas amounted to 7% of the protein ingredients. Unspecified vegetable protein responded for 8% of protein ingredients as vegetable protein, micronized protein, or hydrolyzed protein.

Wheat flour or bulgur was the most common carbohydrate source. Vegetables (carrots, pumpkin, zucchini, aubergine, kale, beetroot, corn, and green jackfruit) were present in 19% of the products. Products containing some sort of sugar (sugar, crystallized sugar, brown sugar, muscovado sugar, glucose syrup, xylose, maltodextrin, dextrose) amounted to 12%. Few products used vegetable fiber (8%). Among those, it was noteworthy the use of cashew fiber, from a typical Brazilian fruit.

Considering fat sources, soybean oil (18%), and other vegetable oils (vegetable oil- 22%; sunflower oil-10%, olive oil- 9%) were the most common sources. Saturated fat sources such as coconut oil and palm oil were found in 8% of the products. Nuts of native Brazilian plants such as Brazil nuts and cashew nuts were also used. Other seeds and nuts found were sesame seeds, sunflower seeds and almonds.

Concerning food additives, 55 of 169 products (32.5%) did not have any food additives. Flavorings were the most frequently used food additives in 41% of products, followed by thickeners and vegetable gums (26%). The flavor enhancer monosodium glutamate was found in 4 products. Other ingredients found were natural seasonings, salt, soy sauce, and minerals and vitamins. Coloring agents were found in 13% of the products. Antioxidants as citric acid and ascorbic acid were found in 6% of products. The sweetener referred to in the ingredients list was sorbitol (6% of products).

Discussion

Practically all plant proteins could be used in the preparation of meat substitutes. However, due to availability, cost, and processing functionality, soy protein, pea protein, and wheat gluten are usually used as the basis for structuring meat substitutes (Schreuders et al., 2019). The vast use of the same protein source might be implicated with some issues, like allergenicity of vegetable proteins and rejection of one or more ingredients (Rubio et al., 2020). Gluten triggers adverse reactions in those with gluten intolerance, wheat allergy, and celiac disease Curtain and Grafe-

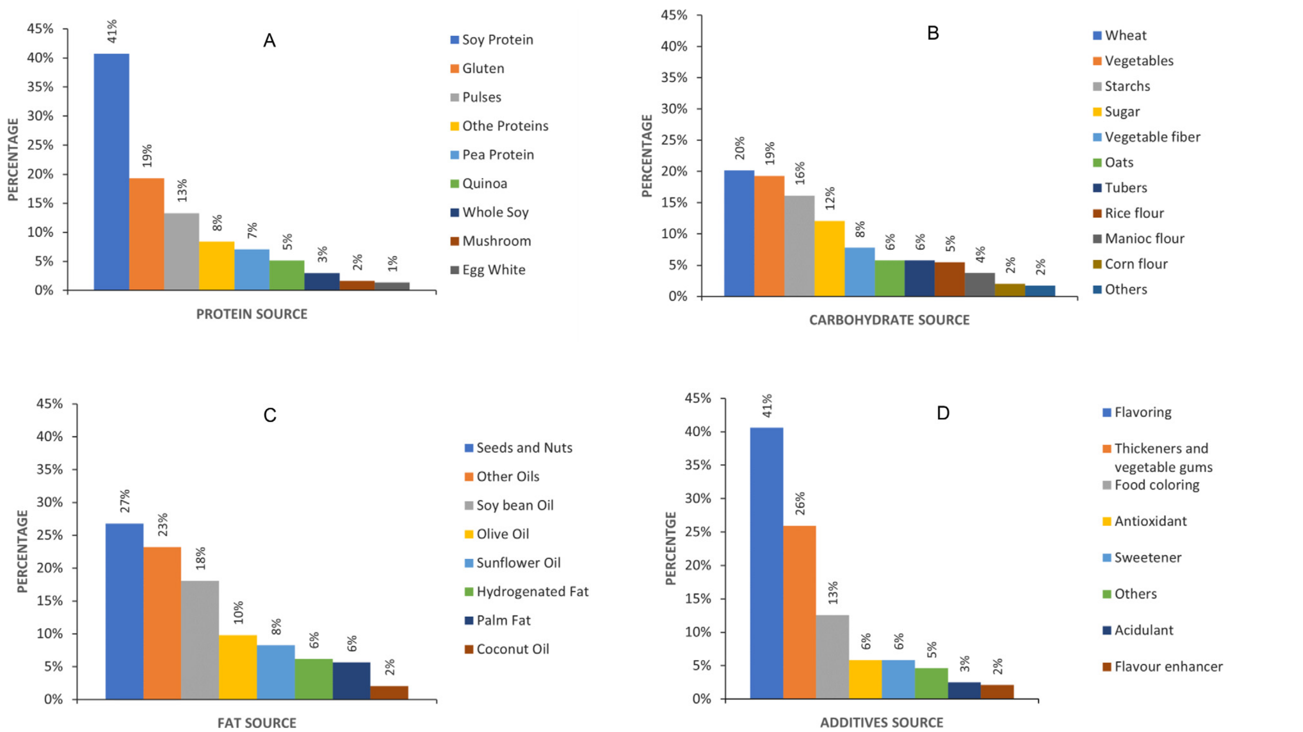

Figure 1. Percentage of ingredients used in the formulation of meat substitutes divided by source of proteins (A), carbohydrates (B), fat (C), and additives (D). Fig. 1 should be printed in color

nauer (2019). found a more diverse protein profile among the products they analyzed with more than two-thirds of the products containing some sort of legume ingredients such as adzuki beans, black beans, chickpeas, and lentils.

The variation of protein content could raise concerns if meat substitutes can be claimed as a meat replacement. While meat mainly consists of protein, fat, and water, plant materials have a much richer and diverse nutrient composition. Clearly, the presence of other components leads to lower protein content (Fasolin et al., 2019). Processing can be used to remove the other components (e.g., to produce protein isolates), but conventional processes require large amounts of energy and water thereby compromising the environmental potential of meat substitutes (Van Der Goot et al., 2016). In addition, the use of highly refined protein ingredients results in a final product without the benefit of health promotion nutrients such as vitamins, minerals, fibers, antioxidants, and anti-inflammatory agents, that otherwise could have a positive effect on consumers‘ health (Fasolin et al., 2019).

Besides, the origin for the apprehension about a too low protein intake in plant-based diets is difficult to identify given that vegetarian populations in western countries are not known for protein deficiencies (Mariotti and Gardner, 2019). According to the Academy of Nutrition and Dietetics (Melina et al., 2016), plant-based diets supply all necessary nutrients for growth and maintenance in all stages of life. Cohort studies demonstrate that protein intake among vegans, vegetarians and semi-vegetarians in the western population is sufficient to meet individual daily requirements, provided energy intake needs are being met (Mariotti and Gardner, 2019). Protein-rich foods, such as legumes, nuts, and seeds, are sufficient to achieve protein adequacy in adults consuming vegetarian/vegan diets (Mariotti and Gardner, 2019). Indeed, the Vegetarian Lifestyle Index (Le et al., 2018) based on the Loma Linda University-Vegetarian Food Guide Pyramid Recommendations (Haddad et al., 1999) considered in the same index component legumes, soy, and meat substitutes. Therefore, meat substitute‘s protein content are expected to be equivalent to the legume´s protein content that originated them, and not similar to meat protein content. Nevertheless, it seems that 2nd generation producers are finding a route to offer meat substitutes that contain higher levels of protein, seeking similarity to the quantities found in meat.

The median amount of carbohydrates became lower with the advanced stages of technology, from traditional products towards 2nd generation products. Teri Lichstein (2020) observed that traditional meat alternatives (18.8 g/100 g) had higher average carbohydrate content than plant-based meat (10.2 g/100 g). Most of the carbohydrates source ingredients are used as thickening agents, contribute to texture and consistency, reduces syneresis, emulsifies oils, binds water, immobilizes fat, and improves rheology. They can also be present as a result of the use of less processed ingredients, such as protein concentrates (Kyriakopoulou, Keppler, and Van Der Goot, 2021).

The 2ndgeneration meat substitutes had a higher amount of total fat and saturated fat than the other products. Fat is an essential component of palatability as it contributes to the juiciness and tenderness of the products (Kyriakopoulou, Keppler, and Van Der Goot, 2021). Also, 2nd generation products that aim to mimic the marbled effect of meat, exhibit visible semi-solid vegetable fats like coconut oil and cocoa butter which are rich in saturated fat (Rubio et al., 2020). However, the high saturated fat amount is one of the biggest criticisms that these products have been facing (Bohrer, 2019). Enhanced intake of saturated fat has been associated with increased risk of cardiovascular disease mortality and incidence of type 2 diabetes (Rocha et al., 2019).

Fibers are non-digestible carbohydrates (Makki et al., 2018), which are present at low levels in meat-based diets (Curtain and Grafenauer, 2019). They interact directly with gut microbiota leading to the production of short-chain fatty acids and regulating gut microbial ecology that impacts host physiology (Makki et al., 2018). As dietary fibers are found exclusively in plants and are not present in meat, the inclusion of meat substitutes in the diet might be considered as an opportunity for consumers to increase their dietary fiber intake (Lichstein, 2020). The median value of dietary fiber did not vary significantly among categories Curtain and Grafenauer (2019). described similar dietary fiber content in meat substitutes available in the Australian market

Fresán et al (2019). found a significant difference between products made of wheat (1.35 g/100 g), soy (6.35 g/100 g), or nuts (3.01 g/100 g). However, it should be noted that processing may reduce the dietary fiber content in protein ingredients from soy and pulse sources (Boukid, 2021). In other words, the ratio protein-fibers in the final product can be controlled by choosing the degree of refined ingredients in the product. The optimal ratio will depend on the actual consumer. Consumers that still eat meat might benefit from meat substitutes high in fibers, while vegan consumers might need a higher protein content. For the latter group, also some micronutrients might be a concern, such as omega-3 fatty acids, vitamin D, vitamin B_{12}, iron, calcium, and zinc (Rocha et al., 2019).

Meat is a good source of vitamin B_{12} whose source is restricted to animal food origin (Bohrer, 2019) Pawlak et al. (2014). studied the prevalence of vitamin B_{12} deficiency among individuals adhering to vegetarian diets and demonstrated that deficiency ranged from 0% to 86.5% among adults and elderly, up to 45% in infants, from 0% to 33.3% in children and adolescents, and from 17% to 39% among pregnant women. Those results demonstrate the urgency vegetarians have of Vitamin B_{12} food sources. Fortifying meat substitutes with vitamin B_{12} might help vegetarian consumers reach their recommended daily intake (Lichstein, 2020). However, the addition of micronutrients poses manufacturers with a dilemma. It is likely that vegan consumers will have limited meat substitutes in their diets anyhow. For flexitarian consumers that replace only part of their meat consumption with meat substitutes, food fortification is less critical. Fortification leads to additional ingredient costs and longer ingredient lists, which are both not appreciated by consumers (Kyriakopoulou, Keppler, and Van Der Goot, 2021). Besides, those products will be mostly used by consumers that still use animal-based product, which might explain why manufacturers are reluctant to fortify their products.

According to the World Health Organization (World Health Organization. 2012), sodium intake should be limited to 2 g per day. The products investigated provided a median value of 23.9% of the recommendation of sodium intake per day. If we consider that in a day, consumers will eat other foods containing sodium, most probably their sodium intake will be higher than recommendation. It was estimated that Brazilian adults consume an average of 3.7 g of sodium per day and that 97.6% of adults consume over the WHO recommendation (Mill et al., 2021). In Brazil, salt added to foods and industrialized products are considered the main dietary sources of sodium, according to the national food acquisition surveys (Sarno et al., 2013). Besides its role as a flavor enhancer and preservative, salt is created during the fractionation process of plant proteins and sometimes added before the structuring process, which leads to the solubilization and unfolding of the protein affecting its structuring potential (Kyriakopoulou, Keppler, and Van Der Goot, 2021). This multi-purpose properties of salt explain the difficulties of lowering it in those food products and all foods (e.g., bread) in general. Nevertheless, excessive sodium intake is associated with increased blood pressure and risk of cardiovascular diseases (Mill et al., 2021), and the industry has long been called to reduce sodium content from its products (World Health Organization, 2014). In Brazil, many voluntary agreements have already been made in this way (Sarno et al., 2013). Regarding the nutrient profile of the products, 2nd generation meat substitutes presented a high percentage of products above the limit for saturated fat (77.8%), while1st generation products and traditional products were adequate. As for sodium, 6.4% of 1st generation products were above maximum limit while 2nd generation products and all but one traditional product were within the acceptable range for sodium. Other studies had similar findings, as Curtain et al (2019) found that only 4% of the products could claim to be low in sodium.

A point that may raise concern among consumers is genetically modified organisms (GMO) crops (Boukid, 2021). Research on consumers preference among Brazilians identified that 22% expect meat substitutes to be non-GMO and 6% not to have soy (GFI, 2020). Soy production in Brazil is associated with deforestation, indiscriminate use of pesticides, contamination of watercourses, and loss of biodiversity (De Castro Lima et al., 2020; Zu Ermgassen et al., 2020). Future demands may result in products based on protein sources that do not require excessive processing (Boukid, 2021), and make use of locally produced native crops, encouraging local development and diminishing the environmental impact of food production (Rubio et al., 2020).

Another point that may raise concern to consumers is the use of food additives. Indeed, recent research associates the consumption of different classes of food additives with negative health impacts such as dysbiosis, thyroid damage, hyperactivity, and even carcinogenic activity (N Kumar et al., 2019.). Much of the recognized flavor of dishes in western diets derive from animal fat (Sha and Xiong, 2020). Hence, artificial meaty flavor has been developed to meet consumer‘s expectations about the taste of meat substitutes. Artificial flavor is also used to mask aftertaste, and the beany and bitter flavors commonly found in TVP and pea protein (P Kumar et al., 2017.). Another commonly used additive, monosodium glutamate, is known to give the umami flavor (Yamaguchi and Ninomiya, 2000). However, its use as a food additive is controversial. Many producers avoid the use of it or replace it with ingredients that naturally contain glutamates (Lichstein, 2020) such as mushrooms and soy sauce, a rich source of umami flavor (Yamaguchi and Ninomiya, 2000). Coloring agents are used to mimic the meat red color or chicken color (Boukid, 2021). Some companies used artificial colorings such as yellow tartrazine and ponceau 4R, which are positively associated with allergic reactions and carcinogenic activity, while other companies used natural coloring agents such as beet juice extract and tomato extract (N Kumar et al., 2019.). An alternative to improve the flavor in meat substitutes without food additives is the employment of different herbs and spices, including those also used in meat processing (Sha and Xiong, 2020).

Health considerations

Many criticisms considering 2nd generation meat substitutes are in relation to the use of highly processed ingredients (Lichstein, 2020). “Ultra-processed foods (UFP) are defined by the NOVA classification of food as

“……industrial formulations typically with five or more and usually many ingredients… Substances only found in ultra-processed products include some directly extracted from foods, such as casein, lactose, whey, and gluten, and some derived from further processing of food constituents, such as hydrogenated or interesterified oils, hydrolyzed proteins, soy protein isolate, maltodextrin, inverted sugar and high fructose corn syrup. Classes of additive only found in ultra-processed products include dyes and other colors, color stabilizers, flavors, flavor enhancers, non-sugar sweeteners, and processing aids such as carbonating, firming, bulking and anti-bulking, de-foaming, anti-caking and glazing agents, emulsifiers, sequestrants and humectants. Several industrial processes with no domestic equivalents are used in the manufacture of ultra-processed products, such as extrusion and moulding, and pre-processing for frying. (Monteiro et al, 2018; Monteiro et al, 2019).

The consumption of UPF has been associated with higher energy intake, adiposity, and at a population level, higher prevalence of obesity in recent observational data (Lawrence and Baker, 2019). The mechanisms proposed for these health associations are that UPF are energy-dense, high in unhealthy types of fat, refined starches, free sugars and salt, and poor sources of protein, dietary fiber, and micronutrients (Monteiro et al., 2018, 2019).

NOVA considers textured and isolated proteins, and gluten as industrial formulations. Therefore, all meat substitutes of the 1st and 2nd generation are ranked as UPF. Still, they do not present many of the negative characteristics of UPF. As seen by our results, calorie density was adequate or below the recommended for 90% of the products. Adequate calorie density is crucial in moderating daily energy intake (Forde et al., 2020) Rolls (2009). demonstrated through a series of designed test meals that energy-dense foods and diets promote greater energy intake and increased body weight. A low energy-density diet can support reductions in energy intake and body weight.

Unhealthy fats refer to trans fats and saturated fats. Trans fats were not present in the products, saturated fat content increased among categories, although our findings were not as high as found in a similar study (Bohrer, 2019). In addition, only a few products contained free sugars (10%). As for the proteins, only traditional products and 10.6% of 1st generation products did not have an adequate amount of protein to be claimed as source or high content of this nutrient, according to Brazilian legislation (RDC nº 429). Dietary fiber content did not differ much in most products, independently from their stage of technology. However, food additives were found in most products (67.5%).

Another alleged problem of UPF is the big-serving sizes. Large serving sizes may lead to increased energy intake and overconsumption (Monteiro et al., 2018, 2019). In fact, we noticed a great variation of serving sizes among the products analyzed which can mislead consumers. This finding suggests the need to standardize the serving sizes of meat analogues according to legislation.

Besides NOVA, consumers in line with the clean food trend are seeking foods without a long list of E numbers or scientific equivalent names on the package (Kyriakopoulou, Keppler, and Van Der Goot, 2021). To keep this public, research on new products might require a change of focus towards developing products with less refined ingredients, natural, recognizable, and chemical-free food (Santo et al., 2020). This might represent a dilemma since products developed on this way will become lower in protein and higher in carbohydrates (starch and fibers), disassociating from the nutritional profile of meat. If products are meant for flexitarians this might not be a problem. How to achieve the texture and taste required by consumers maintaining high quality in nutrients composition and not using highly processed ingredients is yet another challenge.

Limitations and future prospects

As we only analyzed the package labels, we had to rely on the manufacture's information. So future studies could to chemical analyzes of the products to see their nutritional composition. Based on that information, guidelines for the consumption of meat substitutes could be developed. Also interest and important is to analyze the digestibility of meat substitutes, most of the studies on digestibility of vegetable protein are made with isolated protein, so it is important to analyze the effect of high moisture cooking extrusion and mixing proteins that happens with 2nd generation meat substitutes.

Conclusion

An urgent need exists for lowering meat consumption in current diet for sustainability reasons. Though it is perfectly possible to have healthy and tasty vegan diets, a choice towards a full vegan diet is difficult for most consumers still. The purpose of meat substitutes, especially those that aim at mimicking the original meat products, (2nd generation meat substitutes) is to help consumers to lower their meat consumption, not fully replacing it, without changing their eating habits. For the public health professionals, it is important to understand that meat substitutes are already a trend, so narrowing the dialogue with the industry in order to encourage sodium and fat reduction, is a good strategy. Besides, meat substitutes may be a possible answer to another public health problem, global warming.

The results presented in this study showed that there was an evolution in the nutritional composition and list of ingredients of meat substitutes from traditional towards 2nd generation products, as seen for technology evolution. The most advanced meat substitutes can be classified as ultra-processed. However, the nutritional profile is not unhealthy as proposed by the NOVA classification and could be part of a healthy diet. Interestingly, new products did not replace their predecessors, demonstrating that there is space for all, both for consumers that expect whole grain plant-based meat substitutes and flexitarians who expect the aesthetic experience of eating meat. In both cases, it is important to celebrate the initiatives of eating sustainably within environmental boundaries.

However, the health aspects still need improvement. Throughout the development of those products the industry was primarily concerned with taste and texture, now technological efforts need to be directed to nutritional solutions such as to reduce the amount of saturated fat maintain the micronutrients and other compounds of plant proteins and reduce the food additives. This will address the health halo that surrounds those products and will attend the growing demand for clean eating. Future research may focus on the development of low-cost natural flavors and food colorants, which will help keeping the health promoting nutrients naturally found in plant proteins. Consumers should pay attention to product labels and choose products according to their frequency of consumption. If consumers aim to replace a large part of their protein intake with meat substitutes, then they need to make their choice carefully and opt for products with higher protein content and lower sodium and saturated fat content. Furthermore, the sustainability performance of meat substitutes will enhance by accepting differences in the nutritional profile compared to meat, especially regarding the protein content. By accepting such differences, for instance, the use of less refined ingredients will result in the reduction of intensive processing usually applied to make these products.

Declarations of Competing Interest

None.

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