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JOURNAL
Current developments in nutrition

DATE DEPOSITED
7 November 2023

Current Developments in Nutrition 7 (2023) 100059

American Society for Nutrition
Excellence in Nutrition Research and Practice

Current Developments in Nutrition CDN

journal homepage: www.journals.elsevier.com/current-developments-in-nutrition

Original Research

A Cross-Sectional Analysis of Products Marketed as Plant-Based Across the United States, United Kingdom, and Canada Using Online Nutrition Information

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A B S T R A C T

Background: The food industry is responding to a rising demand for plant-based foods by developing and marketing an ever-wider range of vegan and vegetarian products under the banner of "plant-based." Understanding the nutritional properties of these products is critical.
Objectives: To assess the number, meal type, and nutritional content of products marketed as plant-based (MaPB) from the perspective of the consumer across multiple sectors in the United States, United Kingdom, and Canada.
Methods: An online search for products MaPB was performed across supermarkets, restaurants, food manufacturers, and plant-based meal delivery companies in the United Kingdom, the United States, and Canada using the terms: "vegan," "vegetarian," and "plant-based." Online nutrition data were extracted, and whole meals that comprised >50% of ingredients such as fruits, vegetables, legumes, nuts, and seeds were identified. The nutritional content of dishes MaPB in restaurants was also directly compared with meat-containing dishes.
Results: Further, 3488 unique products were identified, of which 962 were whole meals and 1137 were a replacement for the main protein component in a meal, including 771 meat alternatives. Across all sectors, 45% of whole meals had >15-g protein, 70% had <10% kcal from saturated fat; 29% had >10-g fiber per meal, and 86% had <1000 mg sodium. At restaurants, 1507 meat-containing dishes were identified and compared with 191 vegetarian and 81 vegan dishes. The meat-containing dishes were higher in protein [35.4 g (24.0–51.4)] compared with vegetarian [19.0 g (13.0–26.1)] and vegan [16.2 g (10.5–23.2) dishes ($P < 0.001$)]. The vegan dishes were low in saturated fat and sodium (SFA: 6.3 g ± 6.4, Sodium: 800 mg (545.0–1410.0) compared with both meat [SFA: 11.6 g ± 10.0; Sodium: 1280 mg (820.0–1952.0)] and vegetarian [SFA: 9.4 g ± 7.6; Sodium: 1011 mg (603.0–1560.0)] options ($P < 0.001$ for all comparisons).
Conclusions: Products MaPB tend to have lower concentrations of saturated fat and sodium than their meat-containing counterparts, but improvements are needed to optimize their nutritional composition.

Keywords: plant-based, vegetarian, vegan, protein, consumer

Introduction

There has been a rapid increase in the consumption of plant-based foods over the past decade. Nearly 1 in 4 Americans (23%) reported eating less meat in the past year than they had previously according to a 2020 Gallup poll [1], and half of all consumers say they are eating more plant-based foods than they ate last year. Flexitarians (a portmanteau of "flexible" and "vegetarian") now

Abbreviations used: MaPB, marketed as plant-based.

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https://doi.org/10.1016/j.cdnut.2023.100059
Received 6 May 2022; Received in revised form 26 November 2022; Accepted 13 February 2023; Available online 25 February 2023

represent 42% of all consumers globally according to a 2020 survey [2], in addition to 6% vegetarian and 4% vegan [2].

An array of vegan and vegetarian products have been developed, created, and marketed to meet the needs of these consumers [3,4]. These products might be direct analogs or alternatives to meat and dairy products, such as soy burgers or almond milk. Other products, rather than aiming to directly replace the animal-derived protein component of the meal with an analog or alternative, might be whole meals that are entirely or mostly made from plants, for example, a black bean and rice lunch with or without egg.

As people move toward replacing more meat or meat-containing products with vegan and vegetarian alternatives [1–4], the nutritional composition of these products has potential implications for both nutritional adequacy and chronic disease risk factors [5,6]. Although the nutritional quality of whole plant-based items such as fruits, vegetables, legumes, and even grains has been well studied [7,8], the nutritional quality of novel vegan and vegetarian products is less well understood [9–11]. Consumption and purchasing trends indicate that they will represent an ever-larger proportion of population diets [1,2, 12,13]. Therefore, there is an urgency to understand the nutritional composition of this growing segment of products.

A burgeoning literature has examined the nutritional composition of these novel vegan and vegetarian products [9, 14–17] and has used academic or scientific definitions to compare individual food items. However, consumers do not make the distinction between "plant-based analog," "plant-based meat alternative." Rather, the limited data available suggests that consumers are guided by simple descriptions such as "plant-based," "meatless," "vegan," "vegetarian," and even simple icons such as the green "V" on vegan products [18–20], with "plant-based" being overwhelmingly the preferred term [18–20]. Furthermore, there is considerable overlap in both the use of these terms and the public's understanding of them. For example, some vegetarian products that contain cheese, cream, or egg are sold in the plant-based sections of supermarkets, and for some consumers, the words "plant-based" and "vegetarian" are interchangeable [19].

The literature has also largely focused on individual items purchased from supermarkets or available from manufacturers [14–17]. This approach limits the generalizability of these findings because although the supermarket-based purchases contribute the largest proportion to average intake per capita, outside-of-home food consumption is also a significant contributor [21–25]. Meal delivery is also on the rise with an analysis across 5 countries finding that 78% of respondents had ordered ≥1 meal prepared away-from-home in the past 7 d [24].

There is therefore a need to assess the nutritional quality of vegan and vegetarian commercial offerings, broadly marketed under the "plant-based" banner through the lens of the consumer—by examining the nutritional composition of the products marketed as plant-based (MaPB) at the supermarket, eating out, and ordering online.

To that end, we sought to understand what products are being MaPB across multiple commercial sectors and document their available nutrient composition data across countries (United States, United Kingdom, Canada), purchasing sectors, and meal categories. These efforts provide a broad snapshot of the nutritional landscape of the growing "plant-based" market and serve to both help further refine clinical and public health guidance and inform manufacturers when formulating new products.

Methods

Sectors

To assess the plant-based market from a consumer's perspective, online searches were performed across 5 major purchasing categories: *1)* supermarkets, *2)* fast-food restaurants, *3)* sit-down restaurants, *4)* plant-based meal delivery, and *5)* manufacturers. In addition, it was intended that data would be collected and analyzed from independent restaurants, hotel, and aero plane menus. However, due to the coronavirus disease 2019 pandemic, the menus (where available on a website) were limited in product number and diversity for these procurement categories. Furthermore, online nutritional information was not available for any of these products, and the protocol was to contact the company to request this information. Owing to widespread closures and staff furlough, it was not possible to collect nutritional information for any of the products in these categories. Therefore, the decision was taken to exclude these 3 sectors. Instead, to understand more about the nutritional content of plant-based offerings for people seeking such products, the nutritional composition of plant-based delivery meals was assessed.

The search was conducted across the United States, the United Kingdom, and Canada from April 2020 through December 2020; additional product updates occurred throughout quality control inspection of the data through April 2021.

Search and retrieval strategy

To understand what products were on offer, and their nutritional composition through the eyes of the consumer, products were only included if they appeared using search terms used and understood by consumers. Given the overlap in the use and understanding of the terms vegan, vegetarian, and plant-based [19, 20], each of these search terms was used for each sector. The definition of MaPB was therefore any item identified using the search terms "vegan," "vegetarian," or "plant-based."

Note—additional search terms: "plant-predominant," "meatless," "meat-free," "meat replacement," "meat alternative," and "dairy alternative," were used but these identified products that had already been found using "vegan," vegetarian," and "plant-based."

Consistent with the aim to understand the nutritional quality of products from the consumer's perspective, the nutritional composition of the whole product as sold and purchased by a consumer was analyzed, whether it was individual sausages MaPB from a supermarket, or a whole ready meal in a supermarket or a whole main from a restaurant. In addition, in order for the reader to make direct comparisons to animal-based products, subanalyses for the individual specific meat- and dairy replacement products (for example, patties, sausages, yogurts, cheeses) available from supermarkets were also carried out.

To understand novel products available to replace animal-derived foods and drinks any items that were whole produce were excluded, for example, cut fruit selections, canned lentils, and any item not intended to replace animal-derived products, for example, breads and fruit juice.

Supermarkets

The top 10 supermarkets based on the most recent market share estimates per country were identified, and their websites were searched using the search terms: "vegan," "vegetarian," and "plant-based."

Manufacturer

To capture the nutritional data from the most exhaustive list of products MaPB as possible, whenever a branded item within supermarkets was found, all products from that brand's website that met the search criteria were extracted. Given the novelty of products MaPB, it was noted that different products from the same manufacturer were cycled for a short period and then replaced with another. Extracting potentially available products from the manufacturers ensured the capture of the fullest range of products.

Plant-based meal delivery companies

To represent the likely behavior of an individual seeking to purchase a plant-based meal for delivery, the search terms "plant-based," "vegan," "vegetarian," and "delivery" were input into the Google search engine, using the largest city in each country as the user location. The data from the top 10 delivery chains were then extracted for each country in the order of appearance. This approach also avoided the duplication of data collection from many of the fast-food and sit-down restaurants that either offered delivery already or commenced offering delivery during the coronavirus disease 2019 pandemic.

Fast-food and sit-down restaurants

The top 10 fast-food and sit-down restaurant chains per market share in each country were identified. The online menus were searched based on whether any item was advertised as vegan, vegetarian, or plant-based, whether with words or an icon.

Comparison between vegan, vegetarian, and meat-containing products

In addition, to understand the choices available to consumers wanting to reduce their meat intake when eating out, all starters, sharers, and whole meals available in each of the top-10 fast-food and sit-down restaurants (using the same criteria as the initial data extraction) were quantified, and a nutritional analysis to compare all menu items that were vegan, vegetarian, and meat-containing was carried out. In this comparison, only the starters, sharers, and whole meals were compared as these are the dishes that are predominantly derived from meat.

Extracting nutritional data

The nutrition contents provided on the online nutrition facts panel, labels, and menus were used. To be included in the final product database, kilocalorie (kcal) and macronutrients per unit serving size had to be provided. Information pertaining to saturated fat, fiber, sugar, and sodium was also extracted. The full micronutrient composition was not available for any product, and individual micronutrients were only available for so few products that analysis of any other micronutrient except for sodium was not possible.

Where possible, total serving size, suggested serving size, and serving size per 100 g were retrieved and/or calculated. Owing to country-level differences in the labeling of sodium compared with salt, salt values were converted to sodium [salt (g) $\times$ 1000 *2.5].

Nutritional quality

To provide more contextual data on the products MaPB in each sector, this study aimed to capture the nutritional quality of the whole meals. The United States, United Kingdom, and Canadian dietary guidelines [25–27] recommend that ~35%–50% of the diet comprises whole plant foods such as fruits, vegetables, legumes, nuts, and seeds, whereas plant-predominant guidelines suggest that >50% of the plate comes from these foods [28]. Therefore, in this analysis, it was considered that whole meals MaPB should have a minimum of 50% of ingredients from fruits, vegetables, legumes, nuts, and seeds. Wholegrains were deliberately excluded from this group because of between-country differences in labeling of wholegrains, and a lack of clear definitions of the term. For products from the United Kingdom and Canada, the percentage weight of ingredients was used. For products in the United States, the ingredients list (absent weights) and visual inspection of the product's associated images from supermarket/manufacturer/restaurant website images and online reviews (for example, from tripadvisor or blog reviews) were undertaken. Two independent ratings of products were undertaken by NG and KCK. The initial concordance between raters was 98%, and discrepancy review resulted in 100% final concordance.

Data processing and analysis

There was a large variety of products available across the various procurement categories. Therefore, the products were subcategorized into separate meal categories: *1)* products intended to be a whole meal; *2)* main protein source; *3)* starter; *4)* side and/or sharing plate; *5)* snacks; *6)* dessert, *7)* sauces/condiments; and *8)* dairy alternatives. Categories were not mutually exclusive; thus, some products were included in multiple categories. Categorizations prioritized the marketing strategy used for the product (that is, sold in the menu section for mains, proteins, sides, etc.), with additional categorizations based on readily accepted cultural food norms. To ensure representative categorizations, products were first coded into these 8 meal categories by 1 reviewer (NG) and a subset of 200 items (identified by random number generator) were coded by a second reviewer (KCK). Concordance between review categories was >95% on the first pass, and discordant categorizations were subsequently discussed and harmonized between reviewers. Discrepancy themes emerged, resulting primarily from country-specific differences in perceptions of foods as meals compared with side-dishes and a second pass of the product database was undertaken to update categorizations for similar products. Specific criteria for assigning a product into a meal category are detailed below:

Whole meal. For all categories including supermarkets, fast-food chains sit-down chains, and plant-based meal delivery, items were coded as a whole meal if they were described as "meal," "main(s)," "entrée," "breakfast," "lunch," or "dinner." Where there was no product description, a subjective decision was made as to whether that item might be considered as a whole meal. As described above, the discrepancies between items were resolved

via discussion. An example of a discrepant item in this category was macaroni and cheese [whether dairy cheese (vegetarian) or a non-dairy cheese (vegan)], which was ultimately coded as both a whole meal and a side dish.

Examples of the whole meal category included:

- Vegan Sticky Miso Aubergine Udon Noodles
- Vegetarian Pork Bao Bun Meal Kit
- Vegan smothered tofu w/ smashed potatoes and gravy

Main protein. This was an umbrella category that aimed to capture all products that were marketed as the main protein component of a meal, whether by the manufacturer, supermarket, restaurant, or delivery company or could reasonably be considered as the main protein by virtue of being a "meat alternative." Products coded as meat alternatives included products that specifically marketed themselves with a word reflective of a typical animal protein product including "patty," "link," or "sausage" or a morpheme such as "beeph" or "chik'n." A list of all terms used to identify meat alternatives is included in the **Supplemental Data**. The meat alternatives were further subcategorized into the specific products they intended to replace (for example, beef burger, sausages, fish fillet) using the product name, morpheme, and online description (for example, a "plant-based alternative to chicken nuggets") as guides. Where it was not clear which specific product a meat alternative was intended to replace, they were not further categorized beyond "meat alternative."

Other products included in this category were categorized as a main protein by how it was presented or described within the packaging, menus, or website. For example, the following were coded as main protein sources: products advertised on menus in entrée categories alongside main meat products; products that were shown on the packaging as being served with starch and/or vegetables/salad; products for which the "serve with" recommendations included starch and/or vegetables/salad; tofu- and tempeh-based items that were not whole meals.

Examples included:

- Buffalo veggie wings
- Plant -based deli slices
- Teriyaki Veggie Burger

Starter. Starters were coded as starters if they were labeled as "appetizers" or "starters" on the website or menu. Where there was no description, subjective judgment was used based on the usual intake of these items. For example, soups and salads (except where explicitly noted as "mains") were coded as starters irrespective of where they appeared in the menu.

Examples included:

- Vegan Spring Rolls (also included as side, sharer)
- Plant -Based Mushroom Arancini (also included as side, sharer)
- Vegetarian Chickpea Tagine

Side/sharer. This was a combined category to reflect items that could be serve as sides or shared plates, or a combination of 2.

Examples included:

- Meat -Free Medium Vegetable & Squash Slice
- Tempeh Spare Ribz Sticky BBQ Sauce
- Fish-Free Tuna Pate

Dairy alternatives. Products were coded as dairy alternatives if they specifically marketed themselves with a word or morpheme reflective of milk, yogurt, or cheese. Morphemes for this category can be found in the Supplemental Data. Products were also coded into this category if they were specifically advertised as a dairy/dairy-free alternative, and/or if they were specifically included in the dairy/milk section of a menu and/or supermarket website.

Examples included:

- Salted Plant Butter
- Vegan Cheese Flavored White Sauce With Soya
- Free From Cheddar Garlic & Chive

Snack. Products were coded as snacks if they contained keywords related to the snack category, including bars, balls, rolls, bites, jerky, chips, and other products categorized as "crunchy" or "crispy" (for example, roasted chickpeas, veggie straws, beetroot crisps). Products that were single-serving, pre-packaged items were coded as snacks unless they met the "whole meal" or "main protein." Products were coded as snacks if they were specifically advertised as snacks, and/or were included in the snack/cupboard section of the websites.

Examples included:

- Vegan Jerky
- Vega Protein Bar Peanut Butter Chocolate
- Plant Choc Toffee Popcorn Bar

Dessert. Dessert products were coded as such if they contained keywords related to the dessert category, including ice cream, cake, brownies, caramel, chocolate bars, cupcakes, flavored biscuits, cookies or cookie dough, or pies. Products were also coded as desserts if they were specifically advertised as a dessert product and/or were included in the dessert section of the menus and/or supermarket websites.

Examples included:

- Luxury Vegan Carrot Cake
- Non-Dairy & Vegan Peanut Butter & Cookies Ice Cream
- Free From Vanilla Ice Cream

Sauces and condiments. Products were coded as sauces, condiments, and dips if they contained keywords, including mayo/mayonnaise, dips, sauces, dressing, and pesto. Products were also coded into this category if they were specifically advertised as such, and/or were included in the sauces, condiments, or dips section of a menu and/or supermarket website.

Examples included:

- Vegan Garlic Salad Dressing
- Sauce & Dip, Dairy Free, So Cheezy
- Vegan Ranch Dressing And Marinade

Quality control. Given the large number of products retrieved in the database, several quality control steps were employed to

ensure the accuracy of the search and nutrient information. Products MaPB that were not novel products or alternatives to animal-based products were quantified, and then manually removed from the database (for example, packaged fruit, baby carrots). Foods were first searched, on a per meal category basis, to ensure the macronutrient values were multiplied by their general calorie content (4:4:9 for carbohydrate:protein:fat) and compared with the retrieved calorie information. Calculated calories that were <90% or >110% of the label calories were re-checked against their online nutrient facts information and input errors were corrected. Nutrient values (kcals, saturated fat, fiber, and sodium) were additionally sorted by quintiles, and the highest and lowest quintiles were manually checked for implausible values for each. As part of quality control, duplicate items were filtered out of the database; only duplicates within a country were removed to allow for capturing of country-specific differences in nutrient content due to different formulations, as well as representative portrayal of country-level statistics. Several strategies were taken to identify duplicates. First, MATCH functions were coded in Excel to identify products with similar names; duplicate products were removed manually upon inspection. This was iteratively performed until the MATCH function yielded the closest product that was not duplicate. MATCH functions were then applied to numeric values, including the percentage of calories coming from fat * the percentage of calories coming from protein, as well as the percentage of calories coming from carbohydrate, and duplicate products were identified and removed. Throughout this process, it was noted that branded items were the most common sources of duplicates within countries (for example, the same brand/flavor of almond milk was identified at multiple supermarkets). Thus, the last duplicate removal step included manual searches of the database, filtered by product brand and procurement categories of major brands/chains, and removal of additional duplicates. Products with missing nutrient values were re-queried as the last quality control step before analyses and updated if nutrient content information was available.

Quantification. As the aims of this analysis were explicitly descriptive in nature and absent null hypotheses, the primary analysis presents descriptive summary statistics. Nutritional analyses of vegan and vegetarian products were carried out separately. ANOVA or Kruskal–Wallis tests were used for the secondary analysis to compare the nutritional content of vegan, vegetarian, and meat-containing dishes. All descriptive summary statistics and graphing were generated in the R Programming Language (R 4.1.0) using the *dplyr* and *ggplot2* packages, respectively.

Results

Upon completion of search, retrieval, and data entry, the MaPB product database contained 4472 products. Following quality control, including the removal of non-novel products or products that were not alternatives to animal-based products, removal of within-country duplicates, and removal of products without complete macronutrient data, 3488 products were included in the final analysis (Supplemental Figure 1, Table 1).

Supermarkets represented the vast majority of the vegan items found in all countries (United States: 690/963 = 72%; United Kingdom: 1096/1449 = 76%; Canada: 336/534 = 63%) (Table 1). The availability of vegan products in the top 10 fast-food and sit-down chains was limited. In Canada, there were only 4 vegan products across the 10 fast-food restaurants; 10 in the United Kingdom and 17 in the United States were identified. For sit -down restaurants, there were only 3 vegan products available in the United States, 20 in Canada, and 38 in the United Kingdom.

TABLE 1
Number of vegan and vegetarian products found per meal and procurement category, per country

	Vegetarian			Vegan		
	USA	UK	Canada	USA	UK	Canada
Procurement category						
Supermarket	57	160	25	690	1096	336
Fast-food	39	2	18	17	10	4
Sit-down	72	44	42	3	38	20
Manufacturer	7	14	5	78	186	161
Delivery	36	21	0	175	119	13
Meal category[1]						
Whole meal	134	80	51	268	355	74
Main protein source	38	108	17	227	544	203
Meat alternative	32	59	13	164	360	143
Starter	26	14	14	13	31	15
Sides and sharers	33	60	18	71	216	45
Dairy alternatives[2]	5	1	2	322	211	164
Snacks	2	7		52	100	36
Deserts		11	5	61	165	38
Sauces and condiments	5	7	1	31	100	16

UK, United Kingdom; USA, United States of America.
[1] Some products were included in >1 meal category.
[2] The dairy products found were specifically advertised as "plant-based" or "vegetarian" and were non–rennin-based cheese products. They have been included here for completeness, but were not analyzed.

There were 1137 main proteins, 962 whole meals, and 697 (vegan) dairy alternatives. Within the main protein category, 771 products were meat alternatives.

The most common meat alternative products were sausages (n = 115) burger patties (n = 107) and chicken nuggets (n = 60). The most common dairy alternative products were milks (n = 192), cheeses (n = 166), and yogurts (n = 93).

Nutrition

Energy

The energy content was available for all 3488 products. The mean energy content of vegan whole meals varied from 305.8 ± 136.3 kcal (n = 72) from manufacturers to 501.0 ± 282.9 kcal (n = 47) in restaurants (Table 2), whereas the mean energy content of vegetarian whole meals varied from 323.1 ± 131.1 kcal (n = 9) from manufacturers to 537.1 ± 254.2 kcal (n = 129) in restaurants (Table 3). The mean energy content of vegan main protein varied from 180.2 ± 93.9 kcal (n = 657) in supermarkets to 604.0 ± 154.4 kcal (n = 4) in restaurants whereas the mean energy content of vegetarian main protein varied from 187.4 ± 106.8 kcal (n = 136) in supermarkets to 499.4 ± 190.5 kcal (n = 11) in restaurants. The sides and sharers followed the same pattern with the restaurants and delivery companies having the most energy content and supermarkets and manufacturers having the least (Supplemental Tables 1 and 2).

TABLE 2
Nutritional composition of vegan whole meal and main protein products, per sector across the United States, United Kingdom, and Canada combined

	Whole meal				Main protein			
	Supermarkets (301)	Restaurant (47)	Manufacturer (72)	Delivery (276)	Supermarket (657)	Restaurant (4)	Manufacturer (279)	Delivery (33)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Kcal/serving	339.0 ± 121.2	501.0 ± 282.9	305.8 ± 136.3	441.3 ± 157.4	180.2 ± 93.9	604.0 ± 154.4	182.7 ± 74.3	265.9 ± 269.4
Kcal (100g)	157.0 ± 87.6	162.6 ± 53.2[1]	155.3 ± 72.7	129.0 ± 47.6[2]	190.9 ± 67.4	233.3 ± 55.0[3]	202.5 ± 54.9	178.1 ± 44.0
Protein (g/serving)	11.2 ± 5.5	16.2 ± 10.8	9.4 ± 4.8	17.4 ± 8.0	10.9 ± 6.1	22.0 ± 11.6	14.6 ± 6.9	16.8 ± 6.0
Protein (g/100g)	5.4 ± 5.1	5.3 ± 2.7[1]	4.5 ± 1.6	5.2 ± 2.4[2]	12.4 ± 7.1	9.1 ± 1.3[3]	16.5 ± 6.4	16.3 ± 8.5
Protein (% kcal)	13.9 ± 6.4	13.3 ± 5.8	13.3 ± 5.7	16.3 ± 6.2	27.9 ± 17.1	13.8 ± 4.3	34.7 ± 15.9	36.3 ± 17.0
CHO (g/serving)	48.8 ± 19.5	60.8 ± 38.1	44.4 ± 22.1	56.3 ± 25.1	14.4 ± 11.6	62.3 ± 10.8	11.2 ± 8.0	27.8 ± 35.0
CHO (g/100g)	23.4 ± 16.5	17.0 ± 5.1[1]	22.6 ± 12.3	16.5 ± 7.0[2]	14.9 ± 9.7	21.4 ± 6.3[3]	12.6 ± 8.2	14.7 ± 6.1
CHO (% kcal)	58.2 ± 14.2	49.3 ± 13.6	57.1 ± 12.5	51.5 ± 14.1	31.6 ± 17.1	43.1 ± 13.7	25.1 ± 14.2	33.6 ± 15.9
Fat (g/serving)	10.2 ± 6.7	21.0 ± 14.5	10.1 ± 6.3	16.9 ± 10.5	8.4 ± 6.1	32.0 ± 14.0	8.8 ± 5.7	10.7 ± 15.3
Fat (g/100g)	4.4 ± 3.4	8.3 ± 4.9[1]	5.1 ± 3.2	4.8 ± 3.1[2]	8.7 ± 5.3	13.1 ± 2.5[3]	9.6 ± 5.2	6.5 ± 3.3
Fat (% kcal)	25.9 ± 13.1	36.9 ± 14.3	28.6 ± 10.9	33.6 ± 14.6	38.7 ± 14.7	46.1 ± 10.2	39.9 ± 15.4	32.2 ± 13.1
SFA (g/serving)[4]	3.4 ± 3.5	4.5 ± 4.1	2.7 ± 2.0	4.3 ±4.2	2.2 ± 2.8	11.2 ± 11.6	2.1 ± 2.8	2.1 ± 2.5
SFA (g/100g)[4]	1.5 ± 1.5	1.9 ± 1.8[5]	1.5 ± 1.3	1.1 ± 1.0[6]	2.1 ± 2.3	4.3 ± 2.1[7]	2.2 ± 2.7	1.5 ± 1.9
SFA (%kcal)[4]	8.7 ± 8.4	8.1 ± 6.0	8.0 ± 6.3	8.8 ± 8.4	9.2 ± 8.4	13.9 ± 11.8	8.9 ± 10.2	6.7 ± 6.5
Sugar (g/serving)[5]	8.0 ± 5.3	10.2 ± 8.7	6.3 ± 4.9	10.7 ± 6.6	2.6 ± 3.1	9.7 ± 8.1	2.0 ± 2.3	4.0 ± 3.9
Sugar (g/100g)[5]	1.5 ± 1.5	2.9 ± 2.0[5]	2.7 ± 1.2	3.0 ± 1.6[6]	2.6 ± 2.5	3.0 ± 2.3[7]	2.2 ± 2.1	2.6 ± 1.4
Sugar (%kcal)[5]	8.7 ± 8.4	8.9 ± 8.1	9.3 ± 6.7	10.4 ± 6.0	6.3 ± 7.6	5.8 ± 3.3	4.6 ± 4.8	5.8 ± 3.1
Fiber (g/serving)[6]	7.0 ± 4.0	7.8 ± 4.6	6.4 ± 4.0	10.3 ± 5.9	4.2 ± 2.4	8.6 ± 4.3	3.6 ± 2.2	5.1 ± 6.2
Fiber (g/100g)[6]	3.1 ± 2.7	2.7 ± 1.0[5]	2.8 ± 1.0	2.8 ± 1.3[6]	4.6 ± 2.6	2.1 ± 1.2[7]	4.0 ± 2.7	2.9 ± 1.7
Fiber (mg/kcal)[6]	22.2 ± 14.2	18.8 ± 13.8	22.9 ± 12.0	25.5 ± 14.3	26.4 ± 17.4	14.2 ± 7.8	21.7 ± 15.1	17.8 ± 11.6
Fiber/CHO[6]	13.2 ± 9.4	15.9 ± 9.7	11.7 ± 7.3	20.3 ± 11.4	19.0 ± 24.3	20.4 ± 13.1	20.6 ± 25.0	14.8 ± 12.9
Na(mg/serving)[7]	586.9 ± 233.1	863.2 ± 531.7	609.6 ± 316.8	654.7 ± 594.3	399.8 ± 191.8	1030.0 ± 554.9	455.1 ± 200.1	429.1 ± 362.5
Na (mg/100g)[7]	310.8 ± 331.5	279.9 ± 108.1[5]	308.9 ± 152.4	185.8 ± 154.9[6]	448.8 ± 219.9	336.7 ± 111.6[7]	520.1 ± 198.1	331.5 ± 144.2
Na (mg/kcal)[7]	2.0 ± 1.1	1.8 ± 0.8	2.1 ± 0.8	1.6 ± 1.5	2.6 ± 1.5	1.7 ± 0.6	2.7 ± 1.2	1.8 ± 0.7

Na, sodium.

[1] Fiber/CHO: percentage of carbohydrate as fiber. Nutrition per 100g only available for 15 products.

[2] Nutrition per 100g only available for 154 products.

[3] Nutrition per 100g only available for 3 products.

[4] SFA content was available for >95% products from supermarkets and manufacturers, >80% from restaurants and >55% of products from delivery companies.

[5] Sugar (total) content was available for >95% products from supermarkets and manufacturers, >80% from restaurants, and >55% of products from delivery companies.

[6] Fiber content was available for >95% products from supermarkets and manufacturers, >80% from restaurants and >55% of products from delivery companies.

[7] Sodium (or salt) content was available for >98% products from supermarkets and manufacturers, >95% from restaurants, and >90% of products from delivery companies.

TABLE 3
Nutritional composition of vegetarian whole meal and main protein products, per sector across the United States, United Kingdom, and Canada combined

	Whole meal				Main protein		
	Supermarket (73)	Restaurant (129)	Manufacturer (9)	Delivery (54)	Supermarket (136)	Restaurant (11)	Manufacturer (16)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Kcal/serving	361.6 ± 166.7	537.1 ± 254.2	323.1 ± 131.1	468.5 ± 154.3	187.4 ± 106.8	499.4 ± 190.5	206.6 ± 86.5
Kcal (100g)	144.3 ± 57.1	181.5 ± 66.8[1]	132.6 ± 30.3	154.1 ± 49.5[2]	190.5 ± 56.8	203.8 ± 66.2[3]	218.9 ± 59.9
Protein (g/serving)	14.7 ± 9.6	21.5 ± 11.2	14.4 ± 3.5	20.2 ± 8.5	9.7 ± 4.2	23.2 ± 6.5	12.0 ± 4.5
Protein (g/100g)	5.7 ± 2.7	7.8 ± 3.9[1]	6.5 ± 3.4	6.1 ± 2.8[2]	11.5 ± 5.4	9.5 ± 0.8[3]	13.9 ± 5.2
Protein (% kcal)	15.9 ± 4.8	16.4 ± 5.3	19.1 ± 6.7	17.8 ± 7.7	27.3 ± 16.7	20.5 ± 6.5	28.0 ± 14.9
CHO (g/serving)	43.4 ± 20.5	57.2 ± 30.7	38.7 ± 16.0	46.0 ± 23.9	16.2 ± 12.4	52.7 ± 24.1	13.1 ± 8.5
CHO (g/100g)	17.4 ± 8.9	17.6 ± 7.0[1]	16.0 ± 3.3	15.8 ± 7.3[2]	15.4 ± 9.4	17.2 ± 7.7[3]	13.9 ± 7.3
CHO (% kcal)	48.6 ± 13.7	43.4 ± 14.7	49.3 ± 9.9	39.5 ± 15.7	31.1 ± 14.7	41.4 ± 10.3	25.9 ± 12.6
Fat (g/serving)	13.7 ± 6.9	24.8 ± 16.2	12.2 ± 7.2	23.4 ± 11.8	9.0 ± 6.6	22.4 ± 11.2	11.7 ± 7.2
Fat (g/100g)	5.6 ± 3.2	9.9 ± 4.5[1]	5.3 ± 2.3	7.0 ± 2.6[2]	8.9 ± 4.7	10.8 ± 4.2[3]	12.0 ± 6.5
Fat (% kcal)	33.6 ± 13.5	40.6 ± 14.9	34.2 ± 10.6	43.9 ± 14.6	39.6 ± 13.1	39.7 ± 8.3	46.4 ± 14.5
SFA (g/serving)[4]	5.8 ± 5.7	9.0 ± 7.3	4.8 ± 2.9	8.3 ± 6.3	2.8 ± 3.3	6.2 ± 3.7	3.9 ± 3.5
SFA (g/100g)[4]	2.3 ± 2.0	3.2 ± 2.5[1]	2.3 ± 1.2	1.9 ± 1.5[2]	2.5 ± 2.3	4.0 ± 0.3[3]	3.8 ± 3.2
SFA (%kcal)[4]	13.9 ± 10.0	14.0 ± 7.6	14.4 ± 6.4	15.3 ± 11.8	10.8 ± 7.4	11.1 ± 7.0	14.0 ± 9.6
Sugar (g/serving)[5]	6.8 ± 4.7	10.5 ± 9.5	4.9 ± 2.6	10.1 ± 5.5	2.4 ± 2.6	7.4 ± 5.3	1.6 ± 0.7
Sugar (g/100g)[5]	2.8 ± 2.0	2.9 ± 2.0[1]	2.6 ± 2.1	3.0 ± 1.2[2]	2.3 ± 1.7	2.5 ± 1.5[3]	1.8 ± 1.2
Sugar (%kcal)[5]	8.4 ± 6.2	8.9 ± 9.4	6.4 ± 2.6	8.2 ± 3.8	4.9 ± 3.9	5.6 ± 2.8	3.9 ± 3.7
Fiber (g/serving)[6]	5.9 ± 3.5	6.4 ± 4.9	4.0 ± 1.4	9.2 ± 4.1	3.6 ± 1.8	7.9 ± 3.6	2.7 ± 1.4
Fiber (g/100g)[6]	2.2 ± 1.2	2.1 ± 1.6[1]	1.2 ± 1.4	2.8 ± 1.0[2]	4.1 ± 1.9	1.7 ± 0.4[3]	2.9 ± 1.6
Fiber (mg/kcal)[6]	17.8 ± 11.4	13.5 ± 13.3	10.1 ± 10.0	19.6 ± 8.4	25.1 ± 16.3	16.0 ± 10.7	13.8 ± 8.0
Fiber/CHO[6]	12.9 ± 9.0	16.4 ± 15.8	4.4 ± 4.4	26.3 ± 17.3	15.1 ± 13.9	18.0 ± 8.1	16.5 ± 18.3
Na (mg/serving)[7]	633.9 ± 258.2	1053.2 ± 106.6	483.3 ± 108.3	681.9 ± 425.1	368.8 ± 174.5	1066.7.0 ± 458.7	599.4 ± 322.7
Na (mg/100g)[7]	272.6 ± 196.1	395.3 ± 176.4[5]	299.4 ± 179.9	240.7 ± 106.3[6]	419.2 ± 190.1	405.7 ± 61.5[7]	672.8 ± 317.8
Na (mg/kcal)[7]	1.9 ± 0.8	2.0 ± 0.8	2.3 ± 0.5	1.4 ± 0.9	2.3 ± 1.2	2.3 ± 0.4	3.3 ± 1.9

Na, sodium.
[1] Fiber/CHO: percentage of carbohydrate as fiber. Nutrition per 100 g only available for 43 products.
[2] Nutrition per 100 g only available for 11 products.
[3] Nutrition per 100 g only available for 3 products.
[4] SFA content was available for >95% products from supermarkets and manufacturers, >80% from restaurants and >55% of products from delivery companies.
[5] Sugar (total) content was available for >95% products from supermarkets and manufacturers, >80% from restaurants, and >55% of products from delivery companies.
[6] Fiber content was available for >95% products from supermarkets and manufacturers, >80% from restaurants and >55% of products from delivery companies.
[7] Sodium (or salt) content was available for >98% products from supermarkets and manufacturers, >95% from restaurants, and >90% of products from delivery companies.

Protein

Data on protein content were available for 3488 products. The mean protein content of vegan whole meals ranged from 9.4 ± 4.8 g (13.3 ± 5.7% kcal) ($n = 72$) from manufacturers to 17.4 ± 8.0 g (16.3 ± 6.2% kcal) ($n = 276$) from delivery companies (Table 2). 427 (out of 697 of the vegan whole meals) had <15 g per meal. The mean protein content for vegetarian whole meals ranged from 14.4 ± 3.5 g (19.1 ± 6.7%) ($n = 9$) in manufacturers to 21.5 ± 11.2 g (16.4 ± 5.3%) ($n = 129$) in restaurants (Table 3). Of the 265 vegetarian whole meals 102 had <15 g.

The mean protein content per serving of vegan main protein options ranged from 10.9 ± 6.1 g (27.9 ± 17.1% kcal) ($n = 657$) in supermarkets to 22.0 ± 11.6 g (13.8 ± 4.3% kcal) ($n = 4$) in restaurants (Table 2). 691 vegan main protein options (out of 974) had <15 g per serving, 400 had < 10 g protein per serving, and 141 had < 5 g per serving. The protein content per serving of vegetarian main protein products ranged from 9.7 ± 4.2 g (27.3 ± 16.7% kcal) ($n = 136$) in supermarkets to 23.2 ± 6.5 g (20.5 ± 6.5% kcal) ($n = 11$) in restaurants (Table 3). One thirty two vegetarian main protein options (out of 162) had < 15 g per serving, 78 had < 10 g per serving, and 22 had under 5 g per serving.

The protein content of 459 vegan meat alternatives ranged from 11.5 ± 5.9 g per serving for chicken burger ($n = 14$) to 20.1 ± 4.9 g per serving in beef fillets ($n = 12$) (Table 4). 280 (out of 459) vegan meat alternative products had < 15 g protein per serving. The nutritional composition of vegetarian meat alternatives can be found in Supplemental Table 3. The protein content per serving of (vegan) dairy alternatives was 2.4 ± 2.6 g for cheese ($n = 155$), 4.0 ± 1.9 g for yogurt ($n = 93$), and 3.4 ± 3.1 g for milks ($n = 192$) (Table 5).

Saturated fat, fiber, and sodium

Saturated Fat. Saturated fat information was available for 2821 products. The mean %kcal saturated fat of all the vegan whole meals for which data were available ($n = 588$) was under 10% kcal for all sectors (Table 2). 506 vegan whole meals (out of 588) had under 10% kcal from saturated fat. By contrast, only 86 (out of 223 for which data on saturated fat was available) vegetarian meals had < 10% kcal from saturated fat (Table 3).

Similarly, percentage kcal saturated fat across all vegan main protein products (Table 2) for which data was available ($n = 789$) was under 10% kcal across all sectors except for the restaurant sector (13.9 ± 11.8%, n=4) whereas the mean vegetarian main protein content ranged from 10.8 ± 7.4% ($n = 131$) in supermarkets to 14.0 ± 9.6% ($n = 15$) from manufacturers (Table 3).

The saturated fat of dairy alternatives were the highest in butter (51%, $n = 25$), cheese (50% kcal, $n = 152$), and yogurt (19% kcal, $n = 92$) (Table 5).

Fiber. Data on fiber content were available for 2739 products. The fiber content in vegan whole meals ranged from a mean 6.4 ± 4.0 g ($n = 69$) from manufacturers to 10.3 ± 5.9 g from delivery companies ($n = 162$) (Table 2) whereas the vegetarian whole meals ranged from a mean 4.0 ± 1.4 g ($n = 9$) from manufacturers to 9.2 ± 4.1 g from delivery companies ($n = 29$) (Table 3). 175 vegan whole meals from all sectors (out of 561 for which data on fiber was available) and 44 vegetarian whole meals (out of 211 for which data on fiber was available) had fiber content of 10 g or more per meal.

Sodium. Sodium content was available for 3439 items. The mean sodium content of vegan whole meals ranged from 586.9 ± 233.1 mg ($n = 301$) from supermarkets to 863.2 ± 531.7 mg ($n = 47$) from restaurants whereas the mean sodium content of vegetarian whole meals ranged from 483.3 ± 108.3 mg ($n = 9$) from manufacturers to 1053.2 ± 106.6 mg from restaurants ($n = 129$). 592 vegan (out of 686 for which data on sodium was available) and 188 vegetarian (out of 260 for which data on sodium was available) whole meals had < 1000 mg sodium per meal.

The mean sodium content of the vegan main protein ranged from 399.8 ± 191.8 mg ($n = 655$) in supermarkets to 1030.0 ± 554.9 mg ($n = 4$) in restaurants and the mean sodium content of the vegetarian main protein ranged from 368.8 ± 174.5 mg in supermarkets ($n = 135$) to 1066.7.0 ± 458.7 mg ($n = 11$) in restaurants.

The mean sodium content of meat alternatives ranged from 311.7 ± 153.1 mg ($n = 41$) in beef mince to 534.4 ± 445.3 mg ($n = 14$) in bacon rashers and in dairy ranged from 61.1 ± 47.3 mg ($n = 12$) in a dessert to 297.1 ± 219.5 mg ($n = 153$) in cheese.

Comparisons of meat products

A total of 1507 meat-containing starters, mains, and side-dishes were found across the top 10 fast-food and sit-down chains in all countries combined (Table 6). This represented 85% of the total. In contrast, there were 191 vegetarian (11%) and 81 (5%) vegan starters, mains, and side-dishes.

The vegan dishes were low in saturated fat and sodium, and high in fiber than both the meat-containing and vegetarian dishes (Table 6).

Nutritional quality

In supermarkets, 123 (41%) of vegan whole meals and 14 (19%) of vegetarian whole meals comprised >50% whole plant-based ingredients (defined here as fruits, vegetables, legumes, nuts, and seeds) compared with 29 (40%) of vegan and 2 (22%) of vegetarian whole meals from manufacturers as well as 146 (53%) of vegan and 25 (46%) of vegetarian whole meals from delivery companies. In restaurants, 131 (13%) of the meat-containing whole meals, 31 (24%) of the vegetarian whole meals, and 15 (27%) of the vegan whole meals comprised >50% whole plant-based ingredients.

Discussion

This study aims to understand what products are being MaPB across multiple commercial sectors and document their available nutrient composition data across countries (United States, United Kingdom, Canada), purchasing sectors, and meal categories. The analysis also aimed to compare the number and nutritional content of meat-containing, vegan, and vegetarian meals available in the largest fast-food and sit-down chains across the countries. Overall, the nutritional quality based on pre-defined parameters of products MaPB was acceptable, and largely met guidelines for protein, saturated fat, and fiber content. However, there were some marked differences between sectors and within both sectors and products that we discuss below.

Plant-based products tend to be marketed as healthy alternatives [29], and consumers often perceive them as healthier

TABLE 4
Nutritional composition of vegan meat replacement products available in supermarkets categorized by the product they intend to replace, across the United States, United Kingdom, and Canada combined

	Any patty[1] (198)	Beef patties (107)	Beef fillet (12)	Meatballs (22)	Beef mince (41)	Pork sausages (115)	Bacon rashers (14)	Deli ham (12)	The chicken breast (16)	Chicken burgers (14)	Fish fillet (15)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Kcal/serving	189.9 ± 75.6	198.3 ± 77.9	175.0 ± 56.4	170.9 ± 56.5	145.0 ± 62.2	156.5 ± 63.7	114.9 ± 65.5	111.2 ± 49.4	161.8 ± 68.0	189.6 ± 115.4	140.9 ± 59.5
Kcal (100g)	194.4 ± 48.9	189.8 ± 42.0	186.5 ± 47.1	184.0 ± 41.8	166.9 ± 40.8	197.3 ± 57.7	180.5 ± 56.3	181.1 ± 47.8	165.8 ± 46.1	202.8 ± 52.1	159.8 ± 57.6
Protein (g/serving)	11.8 ± 7.4	14.8 ± 7.5	20.1 ± 4.9	13.0 ± 3.9	16.3 ± 5.0	12.4 ± 6.0	14.6 ± 9.0	15.2 ± 5.3	19.1 ± 6.3	11.5 ± 5.9	10.4 ± 6.5
Protein (g/100g)	12.0 ± 6.2	14.3 ± 6.1	21.7 ± 4.0	14.6 ± 4.4	19.2 ± 3.4	16.1 ± 7.2	21.9 ± 4.0	25.2 ± 5.1	19.9 ± 3.7	13.4 ± 4.9	11.9 ± 6.2
Protein (% kcal)	25.2 ± 13.7	30.4 ± 13.7	48.2 ± 11.7	32.3 ± 10.1	48.9 ± 14.1	33.3 ± 13.8	51.0 ± 12.2	57.0 ± 9.3	49.9 ± 9.4	26.9 ± 10.8	34.0 ± 21.2
CHO (g/serving)	14.1 ± 8.8	12.2 ± 9.6	6.0 ± 5.2	9.1 ± 7.1	6.5 ± 4.2	8.2 ± 4.4	6.2 ± 4.5	5.8 ± 2.5	7.5 ± 5.0	12.8 ± 9.1	11.4 ± 9.6
CHO (g/100g)	14.9 ± 7.8	12.0 ± 7.5	6.5 ± 5.5	9.2 ± 3.7	7.9 ± 4.9	10.6 ± 5.2	9.2 ± 4.6	9.8 ± 4.1	7.8 ± 4.2	13.3 ± 6.4	13.3 ± 10.7
CHO (% kcal)	31.5 ± 16.1	26.4 ± 16.4	14.6 ± 11.4	21.9 ± 13.0	19.6 ± 11.0	23.5 ± 13.5	21.4 ± 10.6	22.0 ± 7.0	20.0 ± 11.8	27.5 ± 13.8	32.2 ± 21.0
Fat (g/serving)	9.4 ± 5.5	10.0 ± 5.8	8.0 ± 5.0	8.8 ± 5.0	6.2 ± 5.4	7.8 ± 4.9	3.5 ± 3.4	3.2 ± 2.8	5.7 ± 5.1	10.1 ± 8.3	6.7 ± 4.6
Fat (g/100g)	9.5 ± 4.5	9.3 ± 4.2	8.4 ± 4.9	9.5 ± 4.5	6.8 ± 4.7	9.6 ± 5.3	6.0 ± 5.5	4.9 ± 3.0	5.6 ± 4.9	10.6 ± 5.6	7.3 ± 4.8
Fat (% kcal)	42.3 ± 12.9	42.8 ± 13.5	37.8 ± 13.1	44.0 ± 13.9	32.8 ± 16.3	40.5 ± 15.6	26.5 ± 17.9	23.4 ± 10.6	26.8 ± 16.4	45.5 ± 16.1	36.3 ± 17.4
SFA (g/serving)[2]	2.0 ± 2.4	2.6 ± 2.7	2.3 ± 2.2	2.4 ± 3.5	3.0 ± 3.6	1.7 ± 1.8	1.7 ± 2.0	1.7 ± 2.2	1.9 ± 2.3	2.3 ± 2.4	1.0 ± 0.7
SFA (g/100g)[2]	2.0 ± 2.3	2.4 ± 2.5	2.3 ± 2.1	2.5 ± 3.3	3.0 ± 3.3	2.2 ± 2.4	2.2 ± 2.3	1.9 ± 2.1	1.9 ± 2.3	2.6 ± 3.0	1.1 ± 0.7
SFA (%kcal)[2]	8.9 ± 9.0	10.5 ± 9.7	10.2 ± 8.0	11.1 ± 12.7	13.2 ± 12.8	9.4 ± 8.9	9.5 ± 9.4	8.6 ± 8.7	8.0 ± 8.5	10.7 ± 11.1	5.3 ± 2.9
Sugar (g/serving)[3]	2.1 ± 1.6	1.8 ± 1.5	1.0 ± 0.5	1.6 ± 1.6	1.2 ± 0.8	1.6 ± 1.2	1.0 ± 0.7	1.7 ± 1.0	1.4 ± 1.7	1.3 ± 1.0	1.9 ± 1.5
Sugar (g/100g)[3]	2.2 ± 1.5	1.7 ± 1.2	1.1 ± 0.6	1.5 ± 1.0	1.5 ± 0.8	2.1 ± 1.7	1.4 ± 1.1	2.9 ± 1.5	1.5 ± 1.6	1.7 ± 1.7	2.6 ± 2.7
Sugar (%kcal)[3]	4.5 ± 3.0	3.8 ± 2.5	2.4 ± 1.7	3.5 ± 2.7	3.9 ± 2.2	4.7 ± 3.5	3.0 ± 1.7	6.7 ± 3.2	3.9 ± 4.8	3.4 ± 3.0	7.6 ± 9.3
Fiber (g/serving)[4]	4.6 ± 2.4	4.5 ± 2.5	3.4 ± 1.9	4.3 ± 1.8	4.3 ± 2.6	3.4 ± 2.2	2.4 ± 2.0	1.4 ± 1.1	5.5 ± 2.8	3.1 ± 1.7	3.2 ± 1.3
Fiber (g/100g)[4]	4.9 ± 2.5	4.6 ± 2.5	3.7 ± 1.9	4.6 ± 1.9	5.1 ± 2.6	4.3 ± 2.4	3.1 ± 2.2	2.2 ± 1.2	6.1 ± 3.6	3.4 ± 1.6	3.9 ± 1.0
Fiber (mg/kcal)[4]	26.8 ± 15.3	26.1 ± 16.0	20.2 ± 10.7	26.0 ± 12.0	33.0 ± 18.7	25.5 ± 18.5	19.1 ± 15.7	15.1 ± 13.2	44.1 ± 38.3	18.0 ± 10.4	28.4 ± 11.1
Fiber/CHO[4]	19.2 ± 16.8	23.2 ± 18.8	37.6 ± 31.3	26.5 ± 19.6	27.5 ± 27.7	18.9 ± 17.1	14.4 ± 20.9	6.3 ± 4.6	46.6 ± 43.9	13.7 ± 10.9	7.8 ± 2.4
Na (mg/serving)[5]	397.6 ± 159.4	422.4 ± 165.3	398.8 ± 174.5	462.7 ± 145.9	311.7 ± 153.1	465.8 ± 206.6	534.4 ± 445.3	397.5 ± 188.4	424.6 ± 177.5	403.6 ± 156.7	391.7 ± 185.2
Na (mg/100g)[5]	417.7 ± 155.8	414.9 ± 135.5	432.8 ± 179.1	515.0 ± 158.9	386.6 ± 187.8	599.0 ± 199.3	852.8 ± 408.6	653.1 ± 213.3	438.0 ± 147.8	481.9 ± 201.3	440.7 ± 158.0
Na (mg/kcal)[5]	2.2 ± 1.0	2.3 ± 0.9	2.4 ± 1.1	2.8 ± 0.7	2.4 ± 1.4	3.3 ± 1.4	5.2 ± 3.1	3.8 ± 1.5	2.7 ± 1.0	2.5 ± 1.2	3.0 ± 1.2

Fiber/CHO: percentage of carbohydrate as fiber. Na, sodium.

[1] Any product sold as a patty including products not specifically named, described, or presented as a replacement product for a specific meat. Examples included: bean, burger, and veggie patty, in addition to beef patties. # 208 products of the total 667 meat replacement products were not included in this analysis because they were breaded, battered, or contained pastry ($n = 113$), it was not clear what products they were seeking to replace ($n = 38$), they were part of a mixed product ($n = 44$), for example, burger with bun and condiments, mince in tomato sauce, or there were fewer than 3 product examples ($n = 13$).

[2] SFA content was available for >95% products.

[3] Sugar (total) content was available for >95% products.

[4] Fiber content was available for >95% products.

[5] Sodium (or salt) content was available for >98% products.

TABLE 5
Nutritional composition of dairy replacement products available in supermarkets categorized by the product they intend to replace, across the United States, United Kingdom, and Canada combined

	Milk[1] (192)	Flavored milk drinks[1] (102)	Cheese (155)	Yogurt (93)	Coffee creamers (52)	Butter (25)	Dessert (16)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Kcal/serving	73.1 ± 39.0	91.7 ± 42.7	131.8 ± 93.2	120.0 ± 46.6	34.5 ± 31.9	201.1 ± 231.3	127.3 ± 91.5
Kcal (100g)	36.1 ± 18.4	39.9 ± 18.7	309.1 ± 78.6	89.9 ± 26.5	251.1 ± 195.3	680.1 ± 107.5	179.4 ± 156.9
Protein (g/serving)	3.4 ± 3.1	3.3 ± 3.1	2.4 ± 2.6	4.0 ± 1.9	1.7 ± 1.1	0.5 ± 0.2	3.3 ± 1.8
Protein (g/100g)	1.6 ± 1.4	1.4 ± 1.3	6.3 ± 7.4	3.1 ± 1.4	12.1 ± 17.1	2.3 ± 2.5	2.7 ± 1.0
Protein (% kcal)	18.0 ± 13.0	13.7 ± 11.3	7.0 ± 6.8	15.0 ± 8.2	13.1 ± 11.8	1.2 ± 1.1	11.2 ± 7.2
CHO (g/serving)	6.8 ± 6.4	11.9 ± 8.1	7.7 ± 6.7	13.3 ± 6.3	4.3 ± 2.5	1.1 ± 0.7	16.4 ± 10.9
CHO (g/100g)	3.4 ± 3.1	5.2 ± 3.6	18.7 ± 8.0	9.8 ± 3.6	39.0 ± 27.4	5.7 ± 4.7	19.0 ± 10.8
CHO (% kcal)	33.3 ± 21.7	46.5 ± 22.6	24.5 ± 9.5	43.9 ± 13.9	51.2 ± 19.8	3.3 ± 2.6	55.7 ± 18.7
Fat (g/serving)	3.8 ± 2.2	3.7 ± 1.8	10.5 ± 8.1	5.9 ± 3.9	2.2 ± 3.0	22.3 ± 25.9	7.0 ± 6.7
Fat (g/100g)	1.9 ± 1.3	1.6 ± 0.8	24.3 ± 6.9	4.4 ± 2.9	13.2 ± 10.6	75.1 ± 12.8	12.6 ± 19.0
Fat (% kcal)	50.5 ± 19.3	42.2 ± 21.2	71.2 ± 10.3	41.3 ± 15.0	55.6 ± 22.6	99.2 ± 4.0	47.1 ± 27.7
SFA (g/serving)[2]	1.2 ± 1.8	1.4 ± 1.7	7.5 ± 6.4	2.8 ± 3.4	0.9 ± 0.5	11.7 ± 14.0	3.9 ± 5.6
SFA (g/100g)[2]	0.7 ± 1.4	0.7 ± 0.9	16.2 ± 5.5	2.1 ± 2.8	7.9 ± 8.2	39.4 ± 20.5	7.1 ± 11.3
SFA (%kcal)[2]	16.4 ± 22.2	16.0 ± 20.8	50.2 ± 18.7	19.0 ± 18.5	28.7 ± 20.5	50.6 ± 21.7	23.3 ± 25.7
Sugar (g/serving)[3]	6.1 ± 12.0	10.9 ± 5.9	1.2 ± 1.6	8.7 ± 4.5	3.5 ± 2.0	0.0	11.4 ± 8.1
Sugar (g/100g)[3]	3.0 ± 5.0	4.8 ± 2.6	2.6 ± 3.2	6.7 ± 3.0	24.3 ± 18.1	0.0	12.2 ± 6.2
Sugar (%kcal)[3]	28.6 ± 37.9	41.3 ± 18.5	3.2 ± 5.0	30.2 ± 13.3	42.6 ± 21.0	0.0	40.8 ± 17.7
Fiber (g/serving)[4]	1.1 ± 0.6	1.4 ± 0.7	1.6 ± 1.3	1.7 ± 1.2	0.8 ± 0.4	0.0	1.4 ± 1.2
Fiber (g/100g)[4]	0.6 ± 0.3	0.6 ± 0.3	3.2 ± 1.7	1.2 ± 0.7	3.7 ± 5.1	0.0	1.1 ± 0.7
Fiber (mg/kcal)[4]	17.4 ± 9.0	16.7 ± 8.8	10.9 ± 6.5	14.5 ± 7.3	15.1 ± 14.5	0.0	11.1 ± 8.8
Fiber/CHO[4]	5.5 ± 6.2	4.0 ± 3.1	16.1 ± 34.7	4.4 ± 4.3	6.4 ± 6.2	0.0	4.3 ± 5.4
Na (mg/serving)[5]	96.7 ± 53.7	117.5 ± 49.7	297.1 ± 219.5	73.6 ± 52.8	20.6 ± 15.7	138.5 ± 163.7	61.1 ± 47.3
Na (mg/100g)[5]	46.9 ± 22.5	50.1 ± 19.9	706.4 ± 268.5	61.9 ± 49.3	122.1 ± 113.3	539.3 ± 223.1	54.6 ± 39.1
Na (mg/kcal)[5]	1.7 ± 1.4	1.7 ± 1.4	2.4 ± 1.0	0.8 ± 0.8	0.7 ± 0.5	0.8 ± 0.4	0.5 ± 0.4

Fiber/CHO: percentage of carbohydrate as fiber. Na, sodium.
[1] Milks were separated into 2 categories–plain milks and flavored milk drinks such as chocolate milkshakes or vanilla-based milk beverages.
[2] SFA content was available for >95% products.
[3] Sugar (total) content was available for >98% products.
[4] Fiber content was available for >95% products.
[5] Sodium (or salt) content was available for >95% products. # 62 of the total 697 vegan dairy replacements were miscellaneous and could not be categorized together–for example, pasta sauces, pesto, and dips.

TABLE 6
Nutrition content of meat, vegetarian and vegan starters, main meals, and side-dishes combined across the United States, United Kingdom, and Canada combined

	Meat (n = 1507)	Vegetarian (n = 191)	Vegan (n = 81)	Significance
Energy (kcal/serving)	685.2 ± 355.3[1,2]	549.1 ± 259.3	558.7 ± 310.4	<0.001
Protein (g/serving)	35.4 (24.0–51.4)[1,2]	19.0 (13.0–26.1)	16.2 (10.5–23.2)	<0.001
CHO (g/serving)	52.0 ± 33.7[1,3]	59.4 ± 33.9	69.7 ± 44.2	<0.001
Sugar (g/serving)	9.4 ± 9.1[1]	9.6 ± 8.7[1]	15.0 ± 12.6[2]	<0.001
Fat (g/serving)	35.4 ± 24.0[1,2]	24.3 ± 16.2	20.4 ± 16.4	<0.001
SFA (g/serving)[4]	11.6 ± 10.0[1,3]	9.4 ± 7.6[1]	6.3 ± 6.4[2]	<0.001
Fiber (g/serving)[5]	4.6 ± 3.1[1,2]	5.9 ± 3.8[1]	8.7 ± 4.1[2]	<0.001
Na (mg/serving)[6]	1280 (820.0–1952.0)[1]	1011 (603.0–1560.0)[1]	800 (545.0–1410.0)[2]	<0.001

Na, sodium.
[1] Significantly different from vegan, $P < 0.001$.
[2] Significantly different from vegetarian, $P < 0.001$.
[3] Significantly different from vegetarian, $P < 0.01$.
[4] SFA content was available for >80% of the products.
[5] Fiber content was available for >80% of the products.
[6] Sodium (or salt) content was available for >90% of the products.

than meat-containing products [18,19]. We found that vegan whole meals met the dietary requirements for saturated fat content across all sectors. In contrast, the vegetarian whole meals exceeded the recommendations across all sectors. A large proportion of these meals were cheese dishes, and this was particularly notable at United States restaurants where cheese and pasta dishes were the only "plant-based" options at many restaurants. This is a striking example of the interchangeability of the terms "vegetarian" and "plant-based," and of the challenge in simultaneously catering for the different motivations the

consumer has in seeking a plant-based meal—whether health, environmental, or animal welfare. More precise definitions of the marketing terms used may help provide clarity for the consumer and facilitate industry benchmarking efforts.

The sodium content of meals MaPB in our study was also low in general for both vegan and vegetarian products across most sectors, and at ~600 mg per supermarket meals. This is particularly striking as many of the meals were convenience meals such as microwaveable servings, which tend to be higher in sodium. Although we did not collect data for meat-containing convenience meals in this study for comparison, previous research has found that standard ready meals in the United Kingdom contain 890 mg (736–969 mg) per serving [30]. At restaurants we found the vegetarian meals again scored poorly—with no difference in sodium content compared with the meat comparators. Overall, our assessment is therefore that products MaPB—particularly vegan products—might facilitate the consumption of a diet limited in both saturated fat and sodium. However, we note the limited options for plant-based products when eating out in the United States, and many of the available products have nutrition profiles associated with an increased risk of cardiovascular disease [31,32].

Plant-based products carry a "health halo" [19,29], and perhaps this arises from the beneficial health effects from whole plant-based diets [7,8]. We therefore wanted to understand how many whole meals MaPB were comprised of >50% whole plant ingredients (defined here as fruits, vegetables, legumes, nuts, and seeds). Overall, we found that < half of all products comprised >50% of these whole plant ingredients, with vegetarian products scoring particularly poorly. Similarly, the fiber content of whole meals was low for all sectors apart from the plant-based meal delivery sector. In our analysis, the main protein component from supermarkets provided ~4 g fiber per serving, compared with ~6.5 g in a supermarket whole meal. This suggests that the additional ingredients in most of the plant-based supermarket meals consist of fiber-poor starches and limited vegetables, nuts, or seeds. This reflects the nature of meat-containing convenience meals, which are also low in vegetables and fiber [33]. For consumers seeking plant-based products for nutritional reasons who rely on front-of-packet labels, the labeling and marketing of many products could be misleading. The exception in our analysis was whole meals from plant-based meal delivery companies, where over half of vegan and 46% of vegetarian delivery meals comprised whole plant ingredients. At a mean 10-g fiber per meal, these meals would provide more than a third of the recommended intake for fiber (28 g/d). We did not assess the price in this analysis, but it is possible that these more specialist delivery companies can include relatively more expensive ingredients such as fruits, vegetables, and nuts because they can charge more. Further work should assess prices across all sectors.

In a meat-containing diet, meat usually provides most of the protein [34], and many Western meals are based around a protein source such as a burger, chicken breast, or fish. For this reason, in this analysis, we wanted to capture the protein content of the food component being marketed as a "main protein." Here, there was considerable variation. The "main protein" alternative offered 20 to 25 g per serving at restaurants, which although lower than their meat-containing options, would ensure protein adequacy in most diets. However, the mean protein content of the "main protein" in supermarkets was only ~10 g per serving. This average hides some key variation because many products such as those made with soy, wheat, and pea-protein provide >15 g per serving, whereas others, such as jackfruit contain <1 g. An audit of plant-based meat alternatives carried out across supermarkets in Sydney, Australia also found a considerable range in the protein content per 100 g, for example, from 2.9–20.9 g for burgers [14]. These findings have important implications for product labeling and nutritional guidelines that we now discuss.

We deliberately performed our data collection through the lens of a person without much nutritional knowledge and in light of the overlap and differing understanding of the terms "vegan," "vegetarian," and "plant-based" [18–20]. We wanted to understand which novel products are visible for a person who is seeking to move away from meat or animal-derived products and toward a more flexitarian diet, both when in the supermarket, ordering food at home or eating out. From our analysis, we believe there are concerns but also opportunities, and these will need to be addressed at the manufacturer, labeling, and nutrition professional levels.

First, as noted above, there are novel plant-based products in supermarkets marketed as a "main protein" that contain <5 g of protein per serving. These include products such as jackfruit, vegetable-filled nuggets, or patties. In contrast, there are novel protein-rich products available in supermarkets that would be suitable for a plant-based diet, but are not signposted this way, either via a supermarket website or on the packaging. An example would be a lentil-based pasta, many of which provide >15-g protein per serving. Only 2 legume-based pasta products were identified using our search criteria in one supermarket in the United States. Manufacturers and supermarkets have an important role to play in guiding consumers who are seeking to consume more plant-based products toward products that help them meet their nutritional requirements. Although front-of-pack labeling requires the kcal, fat, saturated fat, and salt/sodium content to be specified, it does not require the protein content to be identified. Thus, a person without nutritional knowledge might assume that a patty of any kind or any labeled meat alternative would be a nutritional equivalent for their usual meat-containing product. We, therefore, believe there is an opportunity for the manufacturers of protein-rich products (whether plant-based "sausages" or a pasta) to help consumers by specifying the protein content per serving.

Likewise, dietary recommendations could be clarified to account for the potentially poorer protein content of some plant-based "main proteins," as suggested by others [35]. For example, the USDA recommends the consumption of 5–7oz (140–200 g) of protein equivalents for adult men and women [36]. Currently, it does not address plant-based equivalents made of non-soy protein. We also note that in general plant-based whole meals were low to moderate in energy content. The energy content of whole meals from supermarkets was only ~360 kcal. This therefore offers considerable scope for nutritional intake, including protein to be modified by additional foods chosen within the diet, and updated dietary guidelines could help support the consumer in making optimal dietary choices.

Likewise, dietitians and health care professionals who provide individual or community-based guidance should highlight the issues we have identified above and give consumers the skills to navigate this rapidly changing landscape. For example, protein

requirements could be ensured by including a serving of lentils or other legumes with a plant-based main protein or consuming a soy-based dessert when the main is a vegan pizza or vegan-cheese-based pasta.

To our knowledge, this is the broadest analysis of the plant-based landscape to date. We captured nearly 4000 unique products across the 3 countries and analyzed our data by sector and meal type. Nevertheless, we acknowledge some limitations. First, we relied on the nutritional information available online for all the products. As we note in the result section, some products had nutritional information that was identified as being incorrect during the quality control (and was excluded), and we have no definitive way of confirming the accuracy of the information provided. Nevertheless, our findings, both for plant-based and meat-containing options, are in line with other studies, including those based on government databases [9,14].

We used standard prespecified metrics to assess the nutritional quality of these products. The nature and degree of food processing are now recognized as an important factor in food's health impact. However, a consensus on grading foods as processed or ultraprocessed is lacking [37,38], and this information is not readily available on nutritional labels currently. We acknowledge that plant-based products, particularly meat alternatives are processed whereas their meat counterparts are not [17]. However, it is worth noting that for many plant-based products, their meat-containing counterpart would also be processed (for example, chicken nuggets, fishcakes).

The aim of our study was to understand the commercial plant-based landscape through the lens of a person without nutritional knowledge, and accordingly only included products that were labeled or marketed as being vegan, vegetarian, or plant-based. For example, if a Chinese restaurant had a tofu-based dish on the menu or a supermarket had a ready meal that was tofu-based but neither of them were advertised as being plant-based, then we would not have included these in our analysis. Therefore, we cannot say that the dietary analysis performed here is necessarily a true and accurate representation of all plant-based products available in the countries studied.

We also emphasize that this analysis is a snapshot of the landscape at the time we did the search (April 2020 through December 2020). Products are reformulated regularly and therefore the reproducibility of this analysis is limited. Our search was limited to 3 Western countries, and there is a need for similar studies in other countries and regions.

Finally, we note that the nutritional content of the products assessed in this study does not necessarily reflect the nutritional content of the whole diet consumed by a person consuming a flexitarian, vegetarian, or vegan diet. As others have noted, healthy and unhealthy choices can be made within any dietary pattern [10]. However, Multiple stakeholders, including funders, food scientists, manufacturers, supermarkets, restaurants, and public health professionals, should work together to ensure that food intake from people choosing plant-based products is as healthy as possible.

Acknowledgments

The authors also acknowledge the assistance of Reema Roda, James Bradfield, Sydney Saxton, Danielle Stephens, Noor Wadi, and Chloe Davis who provided some assistance with data collection.

Author contribution

The authors' responsibilities were as follows—NG conceived the study. NG, KK, and CM refined the study design. DW, EW, IU, OT, RG, and CM carried out the data collection. NG, KK, and CM produced the first draft of the manuscript. DW, EW, IU, OT, and RG provided additions and corrections. All authors have read and approved the manuscript.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Funding

The authors received no specific funding for this work.

Author disclosures

NG has a nutrition consultancy firm that occasionally advises companies on plant-based nutrition. RG started a 501c3 non-profit called preventative protein. All other authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cdnut.2023.100059.

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