



Nutrient Requirements and Optimal Nutrition

Protein Adequacy, Plant Protein Proportion, and Main Plant Protein Sources Consumed Across Vegan, Vegetarian, Pescovegetarian, and Semivegetarian Diets: A Systematic Review

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ABSTRACT

Background: There are several types of plant-based diets, with unknown differences across diets on total/plant protein intake and variety of plant protein sources consumed.

Objectives: This systematic review aimed to compare total protein intake, proportion of plant proteins, and main plant protein sources consumed across 4 primarily plant-based diets: vegan, vegetarian, pescovegetarian, and semivegetarian.

Methods: We included observational studies reporting on protein intake and/or protein sources in generally healthy adults that were published between 2002 and 2023. We determined the following: 1) % energy from total and plant protein; 2) the proportion of plant protein relative to total protein intake; and 3) main plant protein sources (median percentage contribution of each source to total plant protein intake; interquartile range) consumed across the 4 diets. The plant protein sources were broadly classified into the following United States Department of Agriculture food groups: grains; nuts and seeds; soy products; and beans, peas, and lentils.

Results: We included 13 studies reporting on protein intake/sources that were conducted in the United States, Europe, and South Korea. Of these, 7 reported on vegan, 11 on vegetarian, 7 on pescovegetarian, and 7 on semivegetarian diets with total protein intake ranging from 10% to 17.4%. Vegan diets had the highest plant protein proportion (range: 77%–98%) and semivegetarian diets the lowest (range: 37%–83%). Plant protein source contribution was the highest from grains (range: 60%–78%). Nuts and seeds were the most consumed in vegetarian diets (7.9%; 2.9%–10.3%) and least in semivegetarian diets (3.7%; 2%–14.8%). Soy products and beans, peas, and lentils were most consumed in vegan diets (17.3%; 16.3%–19.9, and 19.6%; 14.6%–21.3, respectively) and least in semivegetarian (3.7%; 1.3%–13.9%, and 8.5%; 5.2%–10.2%) diets.

Conclusions: Vegan diets has the highest plant protein proportion and a variety of plant protein sources, while semivegetarian diets has the lowest plant protein proportion and mainly relied on grains as a plant protein source.

Keywords: plant-based diet, vegan, vegetarian, pescovegetarian, fish eater, flexitarian, semivegetarian, protein intake, plant protein, protein source

Introduction

Plant-based diets are defined as having a primary intake of foods from plant sources such as wholegrains, fruits, vegetables, legumes/pulses, and nuts and seeds [1,2]. Four plant-based diets that are often described in the literature are vegan, vegetarian, pescovegetarian and semivegetarian diets. These diets differ in the extent to which they include animal protein sources (Table 1) [1,3,4]. Semivegetarian or “flexitarian” diets have grown in popularity, especially in high income countries such as

Switzerland, Netherlands, and Sweden [5–7]. They are described as primarily vegetarian diets that include meats, dairy, eggs, poultry, and fish occasionally or in reduced amounts [1].

Proteins are essential macronutrients that play critical roles in normal body functions such as expression of DNA and RNA, biochemical reactions, chemical messaging, transporting proteins, fluid balance, immune function, and muscle support, as well as regulation and growth [8,9]. In the United States, the recommended protein intake for adults is 0.8–1 g/kg body weight/d representing roughly 10%–35% total energy from

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TABLE 1
Sources of protein across various types of plant-based diets as defined by the WHO and grouped according to the USDA's food categories.

Plant-based diet definition ¹		Plant protein sources ²				Animal protein sources ²				
		Grains ³	Nuts and seeds	Soy products	Beans, peas, and lentils	Eggs	Dairy ⁴	Seafood	Poultry	Meats
Vegan	Excludes animal products including meat, dairy, fish, eggs, and honey	X	X	X	X	—	—	—	—	—
Ovovegetarian	Excludes meat, poultry, fish, and dairy products but includes eggs	X	X	X	X	X	—	—	—	—
Lactovegetarian	Excludes meat, poultry, fish, and eggs but includes dairy products such as milk, cheese, yogurt, and butter	X	X	X	X	—	X	—	—	—
Lacto-ovo vegetarian	Excludes meat, poultry, fish but includes dairy and eggs	X	X	X	X	X	X	—	—	—
Pescovegetarian/ pescatarian	Includes fish, dairy, and eggs but not meat	X	X	X	X	X	X	X	—	—
Semivegetarian/ flexitarian	Primarily vegetarian but includes meat, dairy, eggs, poultry, and fish on occasion, or in small quantities	X	X	X	X	X	X	X	X	X

Abbreviations: WHO, World Health Organization; USDA, United States Department of Agriculture.

¹ The plant-based diets definitions were retrieved from the World Health Organization [1].

² Plant and animal protein foods were grouped according to USDA food groups [3].

³ Grains including both wholegrains and refined grains were included as a plant protein source as they were found to be the largest plant protein sources consumed in Africa, Central America, Asia, and Europe, providing on average more protein in the diet than meat products [4].

⁴ Dairy foods included milk, yogurt, and cheese [3].

protein [10,11]. The European Food Safety Authorities recommend consumption of ≥ 0.83 g of protein/kg body weight/d for adults [12]. Protein intake was shown to be adequate in high income populations irrespective of the diet [13–16]. Adults from high income countries, including France, Netherlands, and the United States reported to consume ~ 100 g of protein/d (~ 1.3 – 1.4 g/kg/d) [15,16].

In addition to the total protein quantity consumed, protein quality is relevant for all diets [17]. Protein quality in foods differs depending on the amino acid profile, digestibility, purity, antinutritional factors, and the effects of processing [18–20]. Protein quality is particularly important for plant-based diets as plant protein sources often have lower protein quality than animal protein sources owing to their lower proportions of certain indispensable amino acids and lower protein digestibility [21]. Plant protein sources such as cereal grains usually contain low levels of the essential amino acid lysine [22,23], while legumes contain lower levels of the sulfur amino acids methionine and cysteine [24–26]. When plant proteins are the primary source of protein in diets, it is recommended that a variety of plant protein foods, such as legumes, nuts, and seeds, are combined with cereals to ensure all essential amino acids are consumed in adequate amounts [4,18,21]. Among plant protein sources, soy is one of the highest quality protein sources, given its high levels of essential amino acids and digestibility [27–30].

The aim of this review was to synthesize the current literature on total protein intake, proportion of plant protein relative to total protein intake, and main plant protein sources across 4 primarily plant-based diets: vegan, vegetarian, pescovegetarian, and semivegetarian.

Methods

Search strategy

A search strategy was developed (Supplemental Table 1) and conducted in PubMed, Web of Science, and Cochrane databases. The keywords included “vegan,” “vegetarian,” “pescatarian,” “semivegetarian,” “flexitarian,” “plant-based diet,” “plant-based food,” “protein source,” “protein intake,” “plant protein,” “animal protein,” “dietary protein,” “fish protein,” “grain protein,” and “vegetable protein,” among others. The studies were screened by 1 investigator (MRR).

The literature search was limited to observational studies with no restriction on study duration to determine dietary intake of study populations freely adopting any of the 4 primarily plant-based diets of interest. The search included studies in English language that were published between 2002 and 2023 regardless of geography. Reference lists of relevant systematic reviews and meta-analyses were screened to identify additional eligible studies that would merit inclusion in this review. The inclusion and exclusion criteria were defined according to the population, intervention, comparison, and outcome (PICO) framework for Cochrane reviews [31]. The PICO criteria were defined as follows:

- 1) Population (P): individuals aged 18 y or older defined by the study authors as vegan, vegetarian, pescovegetarian/pescatarian, or semivegetarian/flexitarian and with no known metabolic diseases such as cardiovascular diseases and diabetes including the presence of insulin resistance, hyperinsulinemia, dyslipidemia, and hypertension.

- 2) Intervention (I): none—only observational studies were included. Observational studies with similar study populations were included if the year of assessment, inclusion criteria, and sample size selected differed between studies.
- 3) Comparator (C): 4 primarily plant-based diets: vegan, vegetarian, pescovegetarian, and semivegetarian.
- 4) Outcome (O): total protein intake, plant protein intake proportion, and the intake of main plant protein sources.

Studies were excluded if they reported on specific populations such as children, adolescents, pregnant/lactating women, adults aged older than 70 y, study populations with health conditions, as well as athletes. The excluded studies reported on plant-based diet interventions such as ready to use therapeutic foods to address malnutrition in low-income and middle-income countries. Finally, we focused on the generally healthy population freely adopting plant-based diets and thus excluded studies reporting on plant-based dietary patterns aimed to reduce risk of cardiometabolic diseases (Dietary Approaches to Stop Hypertension diet and Mediterranean diet). Although the Mediterranean diet being a primarily plant-based diet in some regions of the world, we did not consider this diet because of it incorporating a wide range of food groups including plant and animal food sources, while vegan, vegetarian, pescovegetarian, and semivegetarian diets mainly excluding or limiting certain animal food sources.

Data extraction

For each included study, relevant information on the used methods and population characteristics was extracted with a focus on the type of plant-based diet assessed, diet definitions used by the study authors, as well as nutrition assessment tools used to determine dietary intakes.

Information on total protein intake based on total energy intake (%), plant protein intake, and plant protein sources consumed across the primarily plant-based diets: vegan, vegetarian, pescovegetarian, and semivegetarian were extracted from the included studies. The proportion of plant protein relative to total protein intake was determined using mean quantities of the reported intake of plant protein over that of total protein intake and was expressed in percent. The reported plant protein sources consumed were grouped broadly corresponding to USDA food groups: grains; nuts and seeds; soy products; and beans, peas, and lentils, respectively [3] (Supplemental Table 2). Examples of foods grouped under grains included cereal-based foods such as breakfast cereals, porridge, white/brown rice, white/brown pasta, white/brown bread, quinoa, corn, and other cereals. Examples of foods grouped under nuts and seeds included all types of nuts, nut butters, and seeds. Examples of foods grouped under beans, peas, and lentils included baked beans, pulses, and hummus. Finally, examples of foods grouped under soy products included tofu, tempeh, and texturized vegetable protein. The percentage of protein from each of the 4 plant protein food categories was determined as the sum of mean intakes of plant protein (g) from each category relative to total protein intake (g).

Mixed plant protein sources such as plant-based milks or beverages and plant-based alternative products were excluded due to the lack of reporting on specific plant protein source used and amounts used in preparation (oat, rice, pea, soy, etc.). The

percentage distribution from grains; nuts and seeds; soy products; and beans, peas, and lentils based on total weight of plant protein foods consumed across the 4 diets were presented as boxplots. The boxplot displays the minimum, interquartile range, median, and maximum for each plant protein source, any outliers were represented as black dots.

Data synthesis and analysis

As the selected studies were heterogeneous in terms of dietary assessments, the definition of plant-based diets and plant-based foods, and outcomes of interest, a meta-analysis could not be conducted. Instead, extracted results for each study were summarized and visualized in tables and figures.

Results

The search strategy yielded 2348 records of which 157 titles were deemed relevant for abstract screening. A total of 86 abstracts full-text screening and 12 full-text records were included in this review. One additional study was identified through reference lists from relevant reviews on plant-based diets, totaling 13 studies that were included in this review (Figure 1). Of these 13 study populations, those included in the studies by Allès et al. [32] and Gehring et al. [33] were derived from the NutriNet-Sante study, while those included in the studies by Papier et al. [34] and Schmidt et al. [35] originated from the EPIC-Oxford Cohort. Although the study cohorts overlap, the selected studies differed by year of assessment, sample size, and inclusion criteria.

Sample sizes of included studies ranged from 21 to 97,124, participants were predominantly female (51%–100%), and ages ranged from 18 to older than 70 y (Table 2) [32–44]. Overall, 7 studies reported on the vegan diet [32–38], 11 studies on the vegetarian diet [32–37,39,40–43], 7 studies on the pescovegetarian diet [33–37,41,43] and 7 studies on the semivegetarian diet [34,36,37,41–44]. From the 13 included studies, 6 used food frequency questionnaires to collect dietary information, 5 used 24-h recalls, and 2 used 3- to 4-d food records. Dietary self-reporting was used in 62% of studies on vegan diets, 45% of vegetarian diets, 43% of pescovegetarian diets, and 23% of semivegetarian diets. As described in Table 2, the most frequently reported definition for vegetarian diets excluded all animal foods except for eggs and dairy also known as the lacto-ovo vegetarians [1]. Only 1 study identified a diet as strict vegetarians, which was defined as consuming each, none, or less than once per month: meat (red meat, poultry), fish, eggs, milk, and dairy products [41]. The semivegetarian diet definitions were inconsistent across studies with none of the studies having the same diet definition (Table 2). The spectrum of semi-vegetarian diet definitions included the following: 1) ≤ 50 g of total meat daily [34]; 2) red meat 3 or fewer times a week [36]; 3) weekly meat consumption frequency as 1 d a week or 2–5 d a week [44]; 4) do eat dairy products and/or eggs, eat some meat (red meat and poultry) ≥ 1 time/mo, and the total of fish and meat ≥ 1 time/mo but < 1 time/wk [41]; 5) do eat dairy products on regular basis but red meat or poultry at a frequency of ≥ 1 time/mo but ≤ 1 time/wk [42]; 6) restrict the intake of meat and some food groups for ≥ 20 y [44]; and 7) reduce consumption of animal source foods [37].

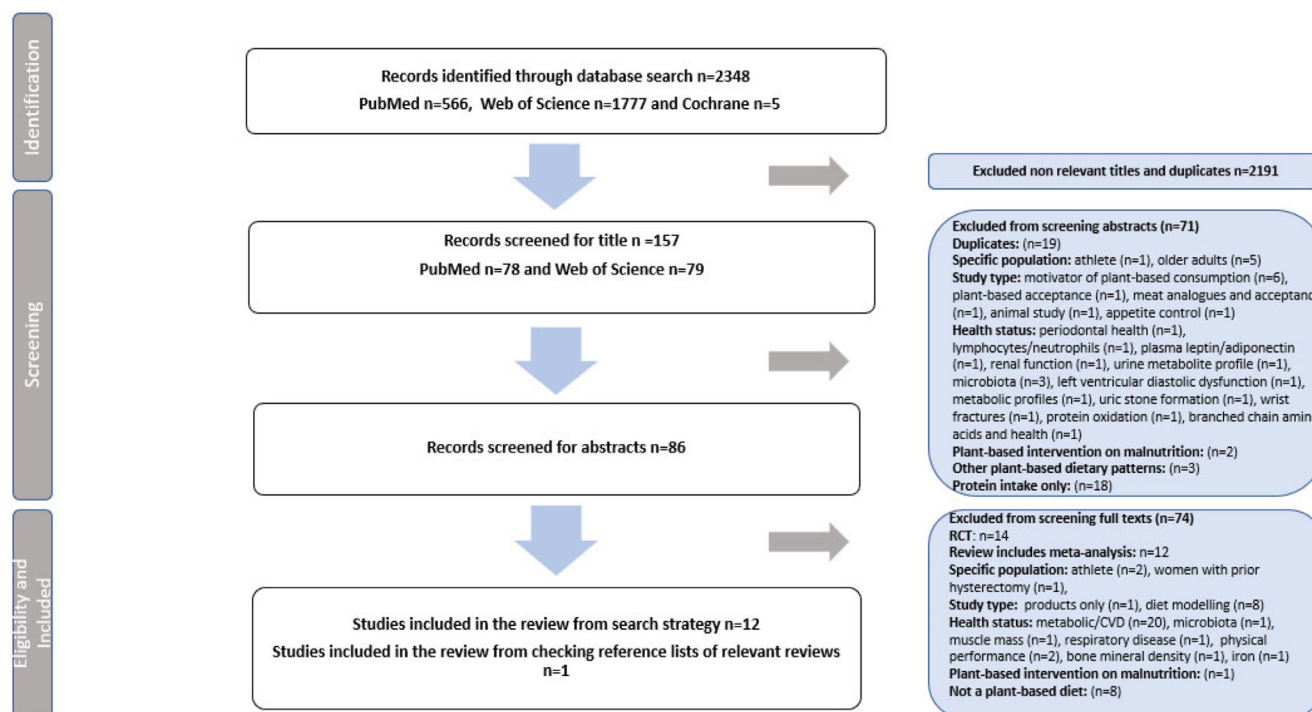


FIGURE 1. Flow chart for review process to obtain observational studies for inclusion in the review.

Total protein intake

Total protein intake was reported in 4 studies on the vegan diet [32,34,35,38], 7 studies on the vegetarian diet [32,34,35,40–43], 4 studies on the pescovegetarian diet [34,35,41,43], and 5 studies on the semivegetarian diet [34,41–44]. The total protein intake presented as a percentage of total energy intake ranged from 12.5% to 13.7% in the vegan diet (Table 2). As for the other diets, the total protein intake ranged from 10% to 16.4% in the vegetarian diet, 13.6% to 17.4% in the pescovegetarian diet, and 13.7% to 16.5% in the semivegetarian diet.

Plant protein proportion

Studies reporting on plant protein intake were limited to 2 studies on vegan diets [32,35], 5 studies on vegetarian diets [32,35,41–43], 3 studies on pescovegetarian diets [35,43,44], and 4 studies on semivegetarian diets [41–44]. The proportion of plant proteins in a vegan diet ranged from 76.6% to 97.6% (Table 2). The proportion of plant proteins ranged from 50% to 95.7% in a vegetarian diet, 48.8% to 78.2% in a pescovegetarian diet, and 37.3% to 83% in a semivegetarian diet.

Main plant protein sources

The studies reporting on main plant protein sources were limited to 6 studies on vegan diets [32–34,36–38], 9 studies on vegetarian diets [32–34,36,37,39,40,42,43], 5 studies on pescovegetarian diets [33,34,36,37,43], and 6 studies on semivegetarian diets [34,37,38,42,43,44]. As shown in Figure 2, total grains contributed most to total plant protein intake in the semivegetarian diet with a median (interquartile range) of 78.1% (76.2–86%), followed by the pescovegetarian 71.3% (60.8–75.1%), vegetarian 68.5% (50.8–75.9%), and vegan 60.3% (51.6–62.6%) diets. Nuts and seeds contributed most to

total plant protein intake in the vegetarian [7.9% (2.9–10.3%)], followed by the vegan [5.2% (2.8–10.3%)], pescovegetarian [4.8% (3–22.5%)], and semivegetarian [3.7% (2–14.8%)] diets. Soy products contributed most to total plant protein intake in the vegan 17.3% (16.3–19.9%), followed by the pescovegetarian 12.8% (8–12.9%), vegetarian 8.7% (2.5–14.9%), and semivegetarian 3.7% (1.3–13.9%) diet. Beans, peas, and lentils contributed most to total plant protein intake in vegan [19.6% (14.6–21.3%)], followed by vegetarian [15.9% (12.1–21.5%)], pescovegetarian [11.1% (9–14.6%)], and semivegetarian [8.5% (5.2–10.2%)] diets. Other protein sources included macroalgae and mushrooms and were reported in 1 study each [37,38]. Of the 13 studies reviewed on plant-based diets, 5 studies mentioned plant drinks or milk alternatives, and from these, only 3 studies referred to specific plant-based meat alternatives, such as vegetarian patties.

Discussion

We reviewed and compared total protein intake, proportions of plant protein and main plant protein sources consumed across 4 different plant-based diets. Our findings show that total protein intake was similar across the plant-based diets and that all diets met the dietary recommendations for protein intake. As expected, most studies assessing vegan, vegetarian, or pescovegetarian diets showed plant proteins as a primary protein source compared with animal protein. From this analysis, only 2 of the 4 studies evaluated showed that those that adhered to a semivegetarian diet consumed more animal than plant protein. Those following a vegan diet consumed the greatest variety of plant protein groups, whereas semivegetarian diets consumed disproportionately high levels of protein from grains.

TABLE 2

Characteristics of selected observational studies ($n = 13$) with nutritional assessment tools, definition of the plant-based diet, and protein consumed across vegan, vegetarian, pescovegetarian and semivegetarian diets.

Author	Country	Sample size (N)	Sampling frame	Age (y)	Sex (%)	Nutrition assessment tools	Definition of diet	Energy (%) from total and plant protein	Proportion of plant protein relative to total protein intake (%)
Vegan diet ($n = 7$)									
Allès et al., 2017 [32]	France	789	NutriNet-Sante: prospective observational cohort from the general population aged 18 y or older	18–30: 28.5% 30–50: 47.9% 50–65: 16.7% 65+: 6.8%	75.4 (F) 24.6 (M)	Three 24-h records 1 weekend day and 2 weekdays	Self-reported: do not eat any meat, fish, eggs, or dairy products	Total proteins ¹ = 12.8 (4.3) Plant proteins ¹ = 9.8 (3)	76.6%
Bradbury et al., 2017 [36]	United Kingdom	248	UK Biobank: prospective cohort study from the general population aged 40–69 y	53.5 ± 8.2 (F) 53.1 ± 7.5 (M)	59 (F) 41 (M)	4 Web-based 24-h record every 3–4 mo	Questionnaire: do not eat red or processed meat, poultry, oily or other fish, eggs or foods containing eggs, or dairy products	Protein intake not reported but the study was included as main protein sources were reported.	Plant protein intake not reported
Papier et al., 2019 [34]	United Kingdom	801	EPIC-Oxford: prospective cohort study from the general population aged 20 y or older	52 ± 11.1 (F) 54.2 ± 11.1 (M)	66.4 (F) 33.6 (M)	112-item semiquantitative FFQ	FFQ: do not consume meat, fish, dairy products, or eggs	Total proteins ¹ = 12.5 (1.8) (F) Total proteins ¹ = 13 (1.7) (M)	Plant protein intake not reported
Schmidt et al., 2016 [35]	United Kingdom	98	EPIC-Oxford: prospective cohort study from the general population aged 20 y or older	40 (35–44)	100 (M)	Semiquantitative FFQ	Self-reported: do not eat any animal products	Total proteins ³ = 12.6 (11.6, 13.9) Plant proteins ³ = 12.3 (11.3, 13.7)	97.6% (M)
Gehring et al., 2021 [33]	France	254	NutriNet-Sante: prospective observational cohort with adults from the general population aged 18 y or older	18–30: 20.9% 31–50y: 50.8% 51–65: 24% >65: 4.3%	73.2 (F) 26.8 (M)	3 nonconsecutive 24-h records for 1 weekend day and 2 weekdays	Self-reported: avoided all animal-based products	Protein intake not reported but the study was included as main protein sources were reported.	Plant protein intake not reported
Grouffh-Jacobsen et al., 2022 [37]	Norway	66	A survey with representative sample of all geographical areas in Norway, age, gender, and educational level	36 ± 13	73 (F) 27 (M)	FFQ with 26 selected food groups	Self-reported: omit all kinds of animal source foods	Protein intake not reported but the study was included as main protein sources were reported.	Plant protein intake not reported

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TABLE 2 (continued)

Author	Country	Sample size (N)	Sampling frame	Age (y)	Sex (%)	Nutrition assessment tools	Definition of diet	Energy (%) from total and plant protein	Proportion of plant protein relative to total protein intake (%)
Elorinne et al., 2016 [38]	Finland	22	Online discussion forum from members of the Finnish Vegan Association	33 (24–50)	73 (F) 27 (M)	3-d food records	Self-reported as vegan	Total proteins ¹ = 13.7 (2.8)	Plant protein intake not reported
Vegetarian diet (n = 11)									
Allès et al., 2017 [32]	France	2370	NutriNet-Sante: prospective observational cohort from the general population aged 18 y or older	18–30: 18.2% 30–50: 46.4% 50–65: 25.4% 65+: 10%	85 (F) 15 (M)	Three 24-h records 1 weekend day and 2 weekdays	Self-reported: do not eat meat but eat other animal products	Total proteins ¹ = 14.2 (3.7) Plant proteins ¹ = 7.2 (2.2)	50.7%
Bradbury et al., 2017 [36]	United Kingdom	3870	UK Biobank: prospective cohort study from the general population aged 40–69 y	52.5 ± 7.8 (F) 52.6 ± 7.7 (M)	68 (F) 32 (M)	4 Web-based 24-h record every 3–4 mo	Questionnaire: do not eat red or processed meat, or poultry, or oily or other fish	Protein intake not reported but the study was included as main protein sources were reported.	Plant protein intake not reported
Bowman, 2020 [39]	United States	675	Cross-sectional data from National Health and Nutrition Examination Surveys	Not reported per diet group	60.4 (F) 39.6 (M)	1-d 24-h record	Questionnaire: includes plant-based foods, eggs, and dairy and excludes meat, poultry, and seafood	Protein intake not reported as %energy but the study was included as main protein sources were reported	Plant protein intake not reported
Kniskern and Johnston, 2011 [40]	United States	21	Arizona State University and surrounding communities from 19 to 40 y	26.2 ± 1.4	100 (F)	4-d food logs 4 consecutive days encompassing 1 weekend day and 3 weekdays	Self-reported vegetarians	Total proteins ⁴ = 13.2 (0.5)	Plant protein intake not reported
Papier et al., 2019 [34]	United Kingdom	6672	EPIC-Oxford: prospective cohort study from the general population aged 20 y or older	52.9 ± 11.2 (F) 56.1 ± 11 (M)	77.2 (F) 22.8 (M)	112-item semiquantitative FFQ	FFQ: do not consume meat or fish but do consume dairy products, or eggs	Total proteins ¹ = 13.8 (1.9) (F) Total proteins ¹ = 13.4 (1.8) (M)	Plant protein intake not reported
Rizzo et al., 2013 [41]	United States	21,799	Cross-sectional from the Adventist Health Study-2 cohort	30–54.9: 39.3% 55–69.9: 31.3% ≥70: 29.1%	63.5 (F) 36.5 (M)	204-item FFQ	FFQ: consume the total of meat, poultry, or fish ≤ once a month, also with no restrictions on eggs and/or dairy products	Total proteins ² = 14.4 Plant proteins ² = 11.9	82.6%

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TABLE 2 (continued)

Rizzo et al., 2013 [41]	United States	5694	Cross-sectional from the Adventist Health Study-2 cohort	30–54.9: 40.1% 55–69.9: 32.9% ≥70: 26.9%	63.2 (F) 36.8 (M)	204-item FFQ	FFQ: consume each of the following not at all, or <1 time per month: meat (red meat, poultry), fish, eggs, milk, and dairy products	Total proteins ² = 14.1 Plant proteins ² = 13.5	95.7%
Schmidt et al., 2016 [35]	United Kingdom	98	EPIC-Oxford: prospective cohort study from the general population aged 20 y or older	43 (36–44)	100 (M)	Semiquantitative FFQ	Self-reported: do not eat meat or fish but do eat dairy products and/or eggs	Total proteins ³ = 13.3 (11.8–14.2) Plant proteins ³ = 7.8 (6.8–9.3)	58.6% (M)
Kwaśniewska et al., 2023 [42]	Poland	21	Cross-sectional survey with representative sample of all geographical areas in Poland, age, gender, and urbanization	<35: 47.6% 35–64: 47.6% >64: 4.7%	57.1 (F) 42.9 (M)	FFQ and a 24-h dietary recall	FFQ: excluded meat (including red meat, poultry, and fish), but consumed other animal products such as eggs, dairy, and honey	Female Total protein ⁵ (% energy) = 10.9 Total protein ¹ (g) = 41.9 (18.7) Plant protein ¹ (g) = 25.5 (10.6) Male Total protein ⁵ (% energy) = 10 Total protein ¹ (g) = 51.5 (14.3) Plant protein ¹ (g) = 30.9 (12)	60.8% (F) 60% (M)
Gehring et al., 2021 [33]	France	500	NutriNet-Sante: prospective observational cohort with adults from the general population aged 18 y or older	18–30: 15% 31–50: 44.8% 51–65: 31.2% >65: 9%	82.8 (F) 17.2 (M)	3 nonconsecutive 24-h dietary records for 1 weekend day and 2 weekdays	Self-reported: avoid meat and fish but not eggs or dairy products	Protein intake not reported but the study was included as main protein sources were reported.	Plant protein intake not reported
Grouffh-Jacobsen et al., 2022 [37]	Norway	128	A survey with representative sample of all geographical areas in Norway, age, gender, and educational level	36 ± 13	83 (F) 17 (M)	FFQ with 26 selected food groups	Self-reported: omit meat and meat products/fish and shellfish but included milk or dairy products/eggs	Protein intake not reported but the study was included as main protein sources were reported	Plant protein intake not reported
Gilsing et al., 2013 [43]	Netherlands	702	Prospective Netherlands Cohort Study on diet and cancer	61.8 ± 1.1 (F) 60.6 ± 4 (M)	69 (F) 31 (M)	Validated 150-item semiquantitative FFQ	FFQ: do not eat meat and fish	Female Total proteins ¹ = 16.4 (5) Plant proteins ¹	50% (F) 56.4% (M)

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TABLE 2 (continued)

Author	Country	Sample size (N)	Sampling frame	Age (y)	Sex (%)	Nutrition assessment tools	Definition of diet	Energy (%) from total and plant protein	Proportion of plant protein relative to total protein intake (%)
								= 8.2 (2.8)	
								Male	
								Total proteins ¹	
								=15.4 (4)	
								Plant proteins ¹	
								=8.7 (2.6)	
Pescovegetarian diet (n = 7)									
Bradbury et al., 2017 [36]	United Kingdom	5701	UK biobank: prospective cohort study from the general population aged 40–69 y	53.9 ± 7.8 (F) 54.1 ± 7.8 (M)	72.6 (F) 27.4 (M)	4 Web-based 24-h record every 3–4 mo	Questionnaire: do not eat red, processed meat, and poultry, but eat ≥1 serving of oily fish or other fish	Protein intake not reported but the study was included as main protein sources were reported	Plant protein intake not reported
Gehring et al., 2021 [33]	France	646	NutriNet-Sante: prospective observational cohort with adults from the general population aged 18 y or older	18–30: 6.5% 31–50: 28.2% 51–65: 41.5% >65: 23.8%	84.5 (F) 15.5 (M)	3 nonconsecutive 24-h records for 1 weekend day and 2 weekdays	Self-reported: avoid meat (red meat, poultry, and processed meat) but not fish	Protein intake not reported but the study was included as main protein sources were reported	Plant protein intake not reported
Gilting et al., 2013 [43]	Netherlands	394	Prospective Netherlands Cohort Study on diet and cancer	60.7 ± 4.3 (F) 60.8 ± 3.7 (M)	62 (F) 38 (M)	150-item semiquantitative FFQ	FFQ: 3 items relating to fish consumption	Female Total proteins ¹ = 17.4 (5.8) Plant proteins ¹ = 8.5 (3.9) Male Total proteins ¹ = 15.9 (5.2) Plant proteins ¹ = 8.3 (3.2)	48.8% (F) 52.2% (M)
Papier et al., 2019 [34]	United Kingdom	4582	EPIC-Oxford: prospective cohort study from the general population aged 20 y old or older	55.7 ± 11.4 (F) 58.3 ± 11.2 (M)	83 (F) 17 (M)	112-item semiquantitative FFQ	FFQ: do eat fish but did not consume meat	Total proteins ¹ = 15.4 (2.2) (F) Total proteins ¹ = 14.8 (2.2) (M)	Plant protein intake not reported
Rizzo et al., 2013 [41]	United States	6583	Cross-sectional from the Adventist Health Study-2 cohort	30–54.9: 40.4% 55–69.9: 33.1% ≥70: 26.5%	67 (F) 33 (M)	204-item FFQ	FFQ: consume fish ≥1 time/mo and red meat and poultry <1 time/mo	Total proteins ² = 14.5 Total proteins ² = 11.4	78.6%
Schmidt et al., 2016 [35]	United Kingdom	98	EPIC-Oxford: prospective cohort study from the	41 (36–45)	100 (M)	Semiquantitative FFQ	Self-reported: do not eat meat but do eat fish	Total proteins ³ = 13.6 (12.3–15.4)	54.4% (M)

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TABLE 2 (continued)

Grouffh-Jacobsen et al., 2022 [37]	Norway	188	general population aged 20 y or older A survey with representative sample of all geographical areas in Norway, age, gender, and educational level	39 ± 16	85 (F) 15 (M)	FFQ with 26 selected food groups	Self-reported: omit meat and meat products but include fish or shellfish/milk or dairy products/eggs	Plant proteins ³ = 7.4 (6.5–8.8) Protein intake not reported but the study was included as main protein sources were reported	Plant protein intake not reported
Semivegetarian diet (n = 7) Papier et al., 2019 [34]	United Kingdom	4650	EPIC-Oxford: prospective cohort study from the general population aged 20 y or older	59.3 ± 12 (F) 62.7 ± 11.9 (M)	81.1 (F) 18.9 (M)	112-item semiquantitative FFQ	FFQ: consumed ≤50 g of total meat (any) daily	Total proteins ¹ = 15.9 (2.2) (F) Total proteins ¹ = 15.2 (2) (M)	Plant protein intake not reported
Bradbury et al., 2017 [36]	United Kingdom	97,124	UK Biobank: prospective cohort study from the general population aged 40–69 y	53.5 ± 8.2 (F) 53.1 ± 7.5 (M)	59 (F) 41 (M)	4 Web-based 24-h record every 3–4 mo	Questionnaire: consumed red meat but 3 or fewer times a week	Protein intake not reported but the study was included as main protein sources were reported	Plant protein intake not reported
Gilsing et al., 2013 [43]	Netherlands	1396	Prospective Netherlands Cohort Study on diet and cancer	61.5 ± 4.2 (F) 61.3 ± 4.3 (M)	65.4 (F) 34.6 (M)	150-item semiquantitative FFQ	Self-reported: weekly meat consumption frequency as 1 or 2–5 d/wk	Female Total proteins ¹ = 16.5 (5.6) Plant proteins ¹ = 7.3 (2.8) Male Total proteins ¹ = 16.2 (5.7) Plant proteins ¹ = 7.8 (3)	44.2% (F) 48.1% (M)
Kim et al., 2015 [44]	South Korea	54	Cross-sectional study with 47–85 y in Seoul and Gyeonggi-do	62.6 ± 9	100 (F)	24-h record for 3 nonconsecutive days	Questionnaire: restrict the intake of meat and some food groups for ≥ 20 y	Total proteins ¹ (% energy) = 14.2 (2.6) Total proteins ¹ (g) = 50 (15.4) Plant proteins ¹ (g) = 41.5 (14)	83% (F)
Rizzo et al., 2013 [41]	United States	4042	Cross-sectional from the Adventist Health Study-2 cohort	30–54.9: 39.2% 55–69.9: 33.4% ≥70: 27.4%	67.3 (F) 32.7 (M)	204-item FFQ	FFQ: do eat dairy products and/or eggs, eat some meat (red meat and poultry) ≥1 time/mo, and the total of fish and meat ≥1 time/mo but <1 time/wk	Total proteins ² = 14.2 Plant proteins ² = 10.6	74.6%
Kwaśniewska et al., 2023 [42]	Poland	982	Cross-sectional survey with representative	<35: 22.7% 35–64: 56.7% >64: 20.5%	64.2 (F) 35.8 (M)	FFQ and a 24-h record	FFQ: do eat dairy products on regular basis	Female Total protein ⁵ (% energy) =	38.9% (F) 37.3% (M)

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TABLE 2 (continued)

Author	Country	Sample size (N)	Sampling frame	Age (y)	Sex (%)	Nutrition assessment tools	Definition of diet	Energy (%) from total and plant protein	Proportion of plant protein relative to total protein intake (%)
			sample of all geographical areas in Poland, age, gender, and urbanization				but red meat or poultry at a frequency of ≥ 1 time/mo but ≤ 1 time/wk	13.9 Total proteins ¹ (g) = 51.3 (24.1) Plant proteins ¹ (g) = 20 (9.6) Male Total protein ⁵ (% Energy) = 13.7 Total proteins ¹ = 71 (30.2) Total proteins ¹ = 26.5 (11.5)	
Grouffh-Jacobsen et al., 2022 [37]	Norway	426	A survey with representative sample of all geographical areas in Norway, age, gender, and educational level	43 \pm 17	51 (F) 49 (M)	FFQ with 26 selected food groups	Self-reported: aim to reduce consumption of animal source foods	Protein intake not reported but the study was included as main protein sources were reported	Plant protein intake not reported

Abbreviation: FFQ, food frequency questionnaire.

¹ These numbers were reported as mean (SD).

² These numbers were reported as the median only.

³ These numbers were reported as the median (interquartile range).

⁴ These numbers were reported as mean (SE).

⁵ These numbers were reported as mean only.

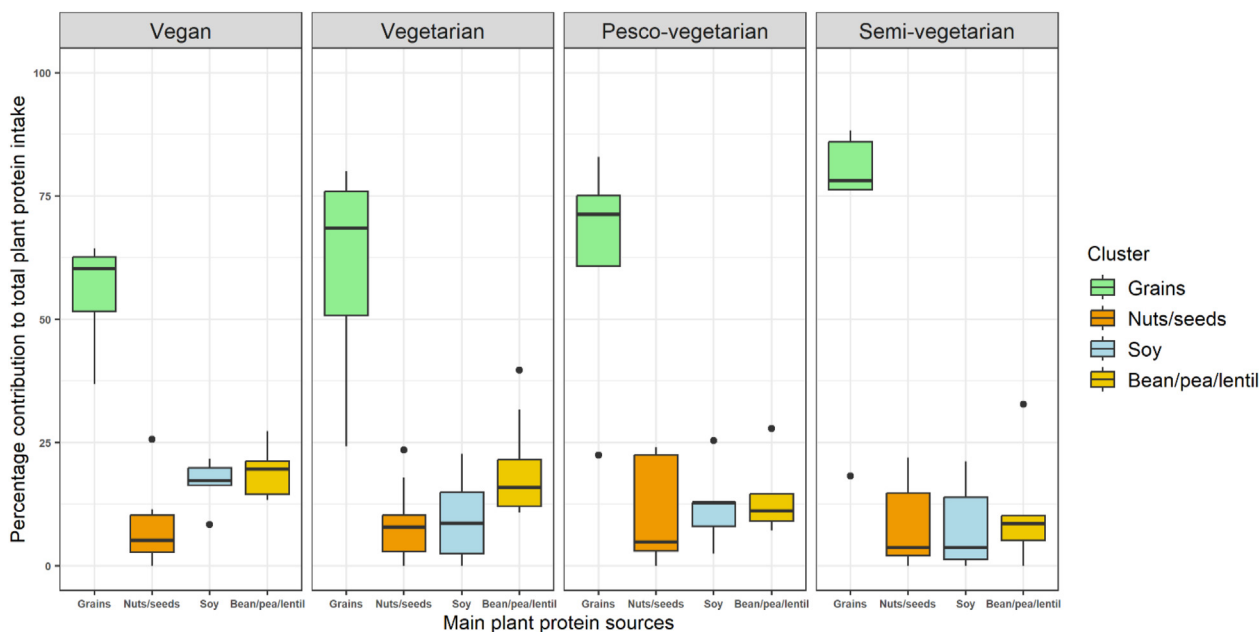


FIGURE 2. Boxplots display the minimum, interquartile range, median, and maximum percentage contribution to total plant intake observed from each main plant protein source group (grains, nuts and seeds, soy, beans, peas, and lentils) across the 4 primarily plant-based diets (vegan, vegetarian, pescovegetarian, and semivegetarian). The end of the left whisker refers to the minimum percentage contribution to total plant intake value. The upper and lower whiskers represent the lower 25% of intake and the upper 25% of intake values. The boxplot indicates the interquartile range also described as the middle 50% of intakes (range between the 25th and 75th percentile). The line that divides the box into 2 parts indicates the median or the midpoint of percentage contribution to total plant intake value. The end of the right whisker refers to the maximum percentage contribution to total plant intake value. Any intake outliers were represented as black dots outside the whiskers of the boxplot.

Total protein intake across plant-based diets

The reported protein intakes across the 4 plant-based diets met the dietary recommendation of 10%–35% total energy from protein intake [11]. Between the plant-based diets, the lowest protein intake was reported from vegan diets compared with vegetarian, pescovegetarian, and semivegetarian ones. Protein intake based on total energy of vegan diets ranged from 12.5% to 13.7%. Two other reviews on protein adequacy in vegan diets reported similar protein intake ranges of 11.1%–14.1% [13] and 13%–15% [45]. A systematic review with participants from high income countries following vegan diets showed protein intake was lowest in vegan diets than other diet groups and vegans consumed slightly below the recommended levels of protein [45]. Another study found 27.3% of vegan participants consumed amounts below the acceptable ranges of protein intakes as per the French nutritional recommendations for adults (10%–20% for adults younger than 70 y and 15%–20% for adults aged older than 70 y), indicating some vegans still do not meet protein intake recommendations and may not be meeting all essential amino acid requirements [32]. Protein intake recommendations for vegetarian diets with low intake of animal proteins were discussed in an observational study including women from the United States, where it was found these diets led to decreased protein bioavailability [40]. To account for lower protein bioavailability from these diets, the study authors suggested an adjustment of protein dietary reference intake for vegetarians from 0.8 to ~1 g/kg body weight [40]. Furthermore, this review did not include any studies on plant-based diets from low-income to middle-income countries, which could have presented with different protein intakes when compared with intake reports from high income

countries. Especially in low-income to middle-income countries, where traditional protein sources like meats, poultry, fish, and dairy are the most expensive components of the food basket and some cultural diets may omit certain animal-based food sources [46]. As a result, individuals in these settings often rely on cereal-based foods as their primary source of daily protein intake, accounting for ~49% of their diet.

Plant protein proportions across plant-based diets

The vegan diet is expected to have a 100% plant protein; however, the reason for the presence of animal protein in vegan diets from this review was due to inconsistencies with study authors recruiting self-identified “vegans” reporting their diet [32,35]. Furthermore, there were only 2 studies in this review that reported plant protein intake in a vegan diet, thus the results cannot be generalized to vegan diets. The proportion of plant protein relative to total protein intake in a semivegetarian diet ranged from 37% to 83%, indicating that in some instances, semivegetarians had a higher intake of animal protein than plant protein [42,43]. This finding of a mixed proportion either from plant or animal protein sources could be attributed to the lack in consistency and consensus on how a semivegetarian or flexitarian diet is defined. The WHO [1] defines semivegetarian diets as primarily vegetarian diets that include meat, dairy, eggs, poultry, and fish occasionally, or in reduced amounts. Hargreaves et al. [47] concur that flexitarian and semivegetarian diets could only be considered plant-based diets if they are more dependent on plant over animal foods in the diet. There were different definitions of a semivegetarian diet used across the 7 studies in this review. These definitions had a general focus on the reduction of animal proteins, especially red meat, but

without any specific guidance on the recommended plant protein sources to include in plant-based diets.

For both health and environmental sustainability reasons, a higher reliance on plant protein sources has been recommended in several global and local dietary guidelines such as in the WHO, Nordic countries, Germany, and the Netherlands [1,48–50]. Although diets high in fruits, vegetables, nuts, and legumes have shown benefits to health such as weight loss and reduced diabetes and cardiovascular disease risk [51,52], it has to be noted a diet modeling study in France found the relationship between the percentage contribution of plant proteins and long-term health was not linear [53]. The study indicated that healthier diets providing adequate nutrients and minimal health risk had a plant protein percentage range from 25% to 70% [53]. When plant protein contribution exceeded >80%, it was predicted that such diets would result in inadequate intakes of nutrients such as iodine, vitamin B-12 (males), bioavailable iron (females), calcium, and EPA and DHA. A similar study was carried out in the Canadian population, and the diet was found to be nutritionally balanced when plant protein sources contributed 25%–74.9% of the total protein intake [54]. Individuals consuming >50% plant protein had lower intakes of total and saturated fat, protein, vitamin D, vitamin B-12, riboflavin, and niacin [55]. In the United States population, it was shown that the gradual increase in plant protein intake led to a decrease in nutrient intakes such as niacin, selenium, sodium, choline, vitamin B-12, vitamin D, and zinc, especially dietary protein, and protein quality too [56]. These studies highlight the importance of nutrient density from the diet, beyond plant protein contribution. These studies in tandem with the results from this review reveal the importance for additional care to be taken for diets high in plant food sources in meeting nutrient requirements such as essential amino acids, vitamins, and minerals often found in high amounts in animal protein foods [15]. The type of protein source of protein quality was also highlighted in a diet modeling study in the United States population, by replacing 25%–50% of amino acids from grain sources with those from legumes, lentils, or non-grain protein sources, improved protein quality of the overall diet [55]. These underscore the importance on complementation of protein sources to not only improve protein quality but also highlight the need to account for other nutrient gaps caused by increased plant protein intake across these diets.

Main plant protein sources across plant-based diets

In Africa, Central America, Asia, and Europe, cereal-based foods were found to be the largest plant protein source in diets, providing on average more protein than meat products [4]. Additionally, studies from the United States and Canada reported breads, rolls, crackers, and grains to be the most consumed plant protein source in the diet [55,56]. Cereal grains represent the main staple food in most parts of the world, therefore are the main energy providers, by contributing primarily to energy from carbohydrates. However, beyond carbohydrates, cereals are also important sources of dietary fibers, and some vitamins and minerals such as thiamin, folate, iron, magnesium, zinc, and selenium [4,57]. Cereals in general have lower protein contents than animal-based foods, and the protein quality is often low due to limited amounts of the essential amino acid lysine [22,23]. In this study, the observation that semivegetarian diets that primarily relied on grains as a plant protein source and least from

the other plant protein sources may not affect overall protein and nutritional quality of semivegetarian diets as the study participants were still consuming increased amounts of animal protein sources when compared with those in the other diets (Supplemental Figure 1). The animal protein sources consumed in vegetarian, pescovegetarian, and semivegetarian diets may compensate for lower lysine levels in cereal grains [58]. Results from this review showed plant protein sources such as nuts, seeds, beans, peas, and lentils were found most consumed in both the vegan and vegetarian diets. Nuts are rich in mono-unsaturated fatty acids, polyunsaturated fatty acids, and dietary fiber [59]. In contrast, legumes such as chickpea, cowpea, lentil, and green pea are excellent sources of protein as well as dietary fiber, iron, zinc, magnesium, and potassium [26]. Despite a high protein content, protein quality of legumes (excluding soybeans) is lower than that in animal sources owing to low levels of sulfur amino acids (methionine and cysteine) [24,25,26]. Studies on vegan and vegetarian diets reported that intakes from high income countries tended to be sufficient across the 9 essential amino acid intakes; however, these diets still show increased risk of inadequacy for vitamin B-12, vitamin D, EPA, DHA, calcium, iron, zinc, and iodine [14]. Followers of the vegan and pescovegetarian diet seemed to have the highest consumption of soy products than the other diets. Soy has a high protein quality that is comparable with that of cow milk and egg proteins, which are often used as standard references for protein quality in foods [60]. Furthermore, soy contains soluble dietary fibers, B vitamins, iron, calcium, zinc, and isoflavones. Including soy in a plant-based diet could therefore contribute to increase the overall protein and nutritional quality of plant-based diets [30].

This review confirms that there are different proportions of plant protein sources consumed across the different populations, with the vegan diet displaying the highest diversity and lowest reliance on cereal-based proteins. As the different plant protein sources display different amino acid profiles, combining these different sources may allow to compensate for any missing essential amino acid and eventually cover all essential amino acid requirements, while providing a variety of other nutrients [58]. Of note, recent dietary guidance in Germany promotes the intake of $\geq 75\%$ from plant-based foods such as fruits, vegetables, legumes and nuts, cereals, cereal products, and potatoes [50]. Countries predominantly relying on plant-based diets such as India, already have this notion of plant protein diversity in dietary guidance. The dietary recommendations in India state “cereals, millets and pulses are major sources of most nutrients” and “vegetarians can derive almost all the nutrients from diets consisting of cereals, pulses, vegetables, fruits and milk-based diets” [61]. Future work could focus on refining definitions for semivegetarian or flexitarian diets clearly in addition to providing specific guidance on the types of plant protein sources and their respective proportions required to maintain both adequate protein quantity and quality, as well as nutrient quality through a diverse food group consumption.

Strengths and limitations

To our knowledge, this is the first comprehensive summary and comparison of total protein, plant protein intakes, and main plant protein sources consumed across vegan, vegetarian, pescovegetarian, and semivegetarian diets. The number of studies assessing plant protein intake and plant protein sources across

plant-based diets in healthy populations is limited. This finding emphasizes the research gap regarding the availability of data on plant protein intake and plant-based meat alternative products in diets. Future observational studies focusing on plant-based diets should aim to collect information on plant protein intake and provide detailed insights into the types of plant-based products consumed. Furthermore, the definition of semivegetarian diets was not conclusive across the considered studies, impeding our ability to fully compare protein intake and protein sources between studies. The review included studies from high income countries with healthy individuals whereas protein intake and quality could be more critical in low-middle income countries or subpopulations such as the elderly or people with specific health conditions. The innovation of plant-based meat alternatives and substitutes is becoming increasingly popular. Current observational studies have identified a gap in capturing the intake of plant-based meat alternatives, resulting in the lack of knowledge regarding the actual consumption of plant-based alternative products within these diets. Furthermore, the challenge lies in capturing the nutrient intake in vegan, vegetarian, pescovegetarian, and semivegetarian diets when plant-based alternative products are included as replacements for traditional plant-based foods. Plant-based beverages were excluded from this review as a main source of protein due to the inability to identify the specific plant protein source used, when indeed considerable amounts of these beverages consumed could be significant to overall protein intake.

In conclusion, across the included studies, an adequate intake of protein was reported for the different diets. Vegan diets had the highest plant protein proportion and reported intake from a variety of plant protein sources, including from grains, beans, peas, lentils, and soy products. Semivegetarian diets had the lowest plant protein proportions and primarily relied on grains as a main plant protein source. Given the growing importance of plant-based diets worldwide, clearer guidance is needed on the adequate contribution from plant protein specifically with regards to the proportions and types of plant protein sources to optimize protein and nutritional quality across the different plant-based diets.

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Author contributions

The authors' responsibilities were as follows – MRR, KAL, MB: developed the study methodology; MRR: carried out the literature search strategy and analysis; MRR: wrote the article with inputs from LSH, KAL, and MB; and all authors: read and approved the final manuscript.

Conflict of interest

MRR, LSH, and KAL are employees of Société des Produits Nestlé S.A.

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Data availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending (e.g., application and approval, payment, other).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.tjn.2024.07.033>.

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