Received: 15 April 2024 | Revised: 20 November 2024 | Accepted: 4 December 2024
DOI: 10.1111/obr.13901

OBESITY Reviews WILEY

REVIEW

Public Health/Nutrition

Plant-based and sustainable diet: A systematic review of its impact on obesity

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Summary

The food system significantly affects the environment through land use, emissions from livestock, deforestation, and food waste. Diet sustainability considers the environmental effects of food production, distribution, and consumption. Animal products emit more greenhouse gases than plant-based foods, prompting a shift towards plant-focused diets for reduced emissions. Sustainable diets, like the EAT-Lancet model, prioritize plant-based foods, adjusting for regional eating habits. These diets aim to be both environmentally friendly and conducive to human health, addressing concerns like obesity and chronic diseases. Obesity is a major global health challenge, and its complex relationship with food production and consumption patterns calls for sustainable solutions to reduce pressure on ecosystems and promote healthier lifestyles. Tackling obesity requires holistic strategies that address not only individual health but also the broader environmental impacts of food systems. A systematic review examined the link between plant-based diets and obesity focusing on studies assessing Body Mass Index (BMI) and body fat assessment. Despite limited research, evidence suggests that adherence to a plant-based diet, particularly a healthy one, is associated with lower obesity rates. More longitudinal and intervention studies are necessary for a stronger consensus on the matter.

KEYWORDS
EAT-lancet, obesity, plant-based diet, sustainability

1 | INTRODUCTION

The dual crises of climate change and obesity pose significant threats to global health and environmental sustainability. The industrialization of agriculture and the rise of processed food diets have contributed to both challenges. Greenhouse gas emissions from agriculture, deforestation, and food waste are exacerbating climate change, while the overconsumption of energy-dense, nutrient-poor foods is fueling the obesity epidemic.[1–4] Plant-based diets, particularly those aligned with the EAT-Lancet diet, offer a promising solution to mitigate both crises.[5]

The food system significantly contributes to the anthropogenic impact on the environment through various factors, including land use for agriculture and grazing, emissions from livestock and fertilizers, deforestation, and food loss and waste.[1–4] It can be inferred that the sustainability of diet refers to the overall environmental impact of food production, distribution, and consumption. When assessing individuals' diets from a climate sustainability perspective, it is therefore essential to consider various aspects: 1) *resource consumption, 2) greenhouse gas emissions production, 3) food waste, 4) food production, and 5) health and well-being.*[1–4]

Balanced diets in terms of climate impact, referred to as sustainable diets, are primarily characterized by plant-based foods such as grains (especially those other than wheat and rice), legumes, fruits and vegetables, nuts and seeds, with low consumption of animal-derived foods (and if consumed, sourced from conditions of welfare, sustainability, and low greenhouse gas emissions)[3,5].

The EAT-Lancet Commission presents a groundbreaking approach to sustainable and healthy eating, also known as the Planetary Health Diet diet.[5] Developed by a group of scientists from various disciplines, the EAT-Lancet diet aims to provide guidelines for a diet which could oppose climate change and safely nurture a growing population. EAT-Lancet diet is defined as a universal reference diet alternative to standard current diets, both able to improve human health and promote environmental sustainability. At its core, the EAT-Lancet diet is a normocaloric diet that emphasizes a plant-based eating pattern. As shown in Table 1, it includes significant portions of calories derived from fruits, vegetables, legumes, and whole grains, a moderate amount of seafood and poultry, with limited consumption of red meat and processed meats. This dietary approach not only aligns with nutritional recommendations for preventing chronic diseases, but also has a lower environmental impact compared to diets high in animal products. Over time, various indices have emerged from this reference diet, including the EAT Lancet Diet Score, the World Index for Sustainability and Health (WISH), the Planetary Health Diet Index (PHDI), the Sustainable Healthy Diet Index (SHED), and the Indice de Dieta Saludable y Sostenible (IDSS).[6–11] In Mediterranean countries, such as Italy, a significant effort has been made to harmonize the global recommendations of the EAT-Lancet diet with the culturally relevant Mediterranean diet, resulting in the EAT-IT diet.[12] This adaptation, designed to align with the specific dietary habits and preferences of the Italian population, provides a 2500 kcal/day dietary plan that promotes both health and environmental sustainability. By incorporating local food choices and culinary traditions, the EAT-IT diet not only makes sustainable eating more appealing and accessible but also ensures a better fulfillment of the specific nutritional needs of the Italian population.[12] In contrast, vegetarian patterns, which range from veganism to flexitarianism, prioritize the exclusion of meat from the diet. Veganism, the strictest form of vegetarianism, eliminates all animal products, including dairy and eggs. Other vegetarian patterns, such as lacto-ovo vegetarianism, allow for the consumption of dairy products and eggs. While vegetarian diets are often motivated by ethical concerns regarding animal welfare, they also offer numerous health benefits, including reduced risk of heart disease, type 2 diabetes, and certain types of cancer.[13,14] While both dietary approaches share a common goal of reducing the environmental impact of food production and promoting human health, they differ in their specific recommendations and underlying philosophies. The EAT-Lancet diet offers a more balanced and flexible approach, accommodating cultural preferences and individual needs, as shown in Table 1.[5] Vegetarian patterns, on the other hand, provide a stricter, more ethically driven approach, focusing on the elimination of meat from the diet.[13,14]

By contrast, the modern diet, heavily reliant on meat, dairy, and processed foods, is a significant driver of environmental degradation. The overconsumption of calorie-dense, nutrient-poor foods, particularly those high in saturated fats, sugar, and sodium, has led to a global obesity epidemic.[1–4] This, in turn, increases the risk of chronic diseases such as heart disease, type 2 diabetes, and certain cancers. The treatment of these conditions places a significant burden on healthcare systems, further straining resources.[5] Climate change and obesity stand at the forefront due to their significant impacts on health and human activities, both individually and in the extent to which they mutually influence each other and share common determinants.[15] The

TABLE 1 Recommended daily intake of various food groups and macronutrients according to the EAT-lancet planetary health diet.

Food groups	Food source	Macronutrient intake grams per day (possible range)	Caloric intake kcal per day
Whole Grains	Rice, wheat, corn, etc.	232	811
Tubers or Starchy Vegetables	Potatoes, cassava	50 (0–100)	39
Vegetables	All types of vegetables	300 (200–600)	78
Fruits	All types of fruits	200 (100–300)	126
Milk and Dairy	Whole milk or similar products	250 (0–500)	153
Protein Sources	Beef, lamb, pork	14 (0–28)	30
	Chicken and other white meats	29 (0–58	62
	Eggs	13 (0–25)	19
	Fish	28 (0–100)	40
	Legumes	75 (0–100)	284
	Nuts and seeds	50 (0–75)	291
Added Fats	Unsaturated fatty acids	40 (20–80)	354
	Saturated fatty acids	11.8 (0–11.8)	96
Added Sugars	All types of sugars	31 (0–31)	120

two themes are so closely linked that some scholars assume that the term 'syndemic' – a 'synergy of epidemics' – can be used, a term that seeks to overcome the historical conception of diseases as distinct units from each other and from the context in which they arise. In this new reading, diseases interact synergistically with each other and with social environments, in particular they are influenced by conditions of inequality and social injustice.[16–18] Syndemics would thus, according to this view, be composed of the triad obesity (malnutrition by excess), malnutrition by defect, and climate change because they occur simultaneously in time and place, interacting with each other at biological, psychological and social levels, and sharing common underlying factors.[19]

Climate change may have contributed to creating an obesogenic environment by pushing people to be more sedentary; caused an increase in the price of fruit and vegetables by discouraging their purchase and consumption; and made it easier to consume energy-dense foods high in sodium, fat, and sugar. On the other side of this vicious circle, increasing food and agricultural production to meet the needs of a growing population with a high prevalence of obesity could increase greenhouse gas emissions from the food system.[19] Obesity could play a role in climate change to the extent that the population with obesity has a high rate of consumption of foods considered to be impactful such as meat, dairy products, and ultra-processed foods stored in unsustainable packaging. At the same time, a less sustainable diet could promote obesity, both in terms of the amount of energy consumed, above requirements and the choice of foods, rich in animal products and ultra-processed energy-dense foods. Nonetheless, there are interesting studies, still emerging, on how obesity can be acted upon in order to achieve beneficial effects on both health and the environment. This new emerging field (which some scholars call 'behavioral eco-wellness') identifies food choices, active travel, but also air quality and immersion in green spaces as a set of actions and conditions that lead to co-benefits for health and environmental sustainability.[20]

The aim of this systematic review is to investigate the relationship between the consumption of sustainable plant-based diets based on the EAT-Lancet reference diet model and the outcomes of overweight or obesity.

2 | MATERIALS AND METHODS

2.1 | Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed.

The studies incorporated in this review were identified through a comprehensive search of three electronic databases, as PubMed, Scopus, and Web of Science, employing specific search terms: "plant-based* AND obesity*," "EAT Lancet* AND obesity*," and "Green Diet* AND obesity*." Additionally, relevant systematic reviews and meta-analyses were examined, scanning reference lists of included articles and including original articles which met our eligibility criteria.

The electronic search spanned from inception to March 15th, 2024. This systematic review was registered in PROSPERO with registration number 518743.

2.2 | Study selection, inclusion, and exclusion criteria

We included original articles written in English with participants aged ≥18 years and a prospective longitudinal or randomized controlled study design. The main outcome studied had to be obesity defined as Body Mass Index (BMI) ≥ 25 kg/m^2 and/or as abnormal or excessive fat accumulation (measured by waist circumference and/or indices of adiposity as visceral fat, subcutaneous from total body CT/dexa, skinfolds), according to the Obesity report of the World Health Organization of June 9, 2021. Moreover, we included studies assessing the effects of a plant-based diet according to the EAT-Lancet model and/or giving details on portions and frequencies of plant-based protein sources and the level of food processing, and, more importantly, excluding definite dietary patterns (e.g. Dietary Approaches to Stop Hypertension - DASH -, vegetarian diet, vegan diet, Mediterranean, Nordish, etc.). This approach in the choice of a plant-based non-defined diet pattern had a relevant impact in study selection process, thus importantly reducing the spectrum of eligible studies. This review evaluates how well an environmentally sustainable pattern addresses the nutritional requirements of obesity, specifically concerning the different caloric intake compared to people without obesity, the exact amount of high biological value proteins, and the micronutrient intake fulfillment, with particular regard to calcium and iron. We applied no country/region, ethnicity, nor date restrictions. Following the elimination of duplicate entries, two independent reviewers (S.P.M. and C.P.) assessed the titles and abstracts derived from the search to select those which met the eligibility criteria. A third reviewer (F.M.) took part in settling any disagreements. Subsequently, upon selecting articles deemed relevant to the review, they proceeded to read the full texts and select them using the abovementioned eligibility criteria.

2.3 | Data extraction

The selected articles underwent comprehensive analysis to extract the following details: authorship, publication year, country of origin, study design, sample size, age of participants, methods for assessing dietary patterns, follow-up information regarding outcome data collection (including tools employed and results obtained), adjustment for confounding variables in the analysis, and primary findings.

2.4 | Quality assessment

Two independent investigators (F.M. and C.P.) conducted the quality assessment.

The Critical Appraisal Checklist for RCT and cohort studies (including longitudinal studies) proposed by Joanna Briggs Institute was used to assess the methodological quality of the selected studies.

The checklist for randomized controlled trials (RCTs) was used, which contained 13 items related to the following critical areas: randomization, allocation, blinding, outcomes, follow-up, statistical analysis, and study design.

In contrast, the checklist for cohort studies included 11 items related to the following critical areas: population characteristics, follow-up, outcomes, exposure, confounders, and statistical analysis.

Each item in the checklist offers four potential responses: "yes," "no," "unclear," or "not applicable." These responses collectively contribute to the overall critical appraisal, informing the decision to include or exclude a study. In cases where the two investigators disagreed in answering the individual items, the opinion of a third investigator (S.P.M.) was sought. Studies in which at least half of the questions received "yes" responses were deemed to possess acceptable quality for inclusion in this systematic review.

3 | RESULTS

3.1 | Study characteristics

Initially, 1516 articles were found on PubMed, Scopus, and Web of Science (Figure 1). A total of 882 duplicates and a further 303 articles were removed based on title and abstract, as they were deemed irrelevant to the review or did not meet the search criteria. The remaining 131 studies were assessed for eligibility. Of these, one was not written in English, one had been withdrawn, 45 were not randomized controlled trials, longitudinal studies or cohort studies, and 77 were on children under the age of 18 or whole families, and were therefore discarded. At the end of this evaluation process, seven studies were included in this systematic review (Figure 1). The assessment of the methodological quality of the selected studies is shown in Figures 2 and 3. One cohort study was discarded, having received negative scores in more than half of the items. For this reason, six studies are included in this systematic review.

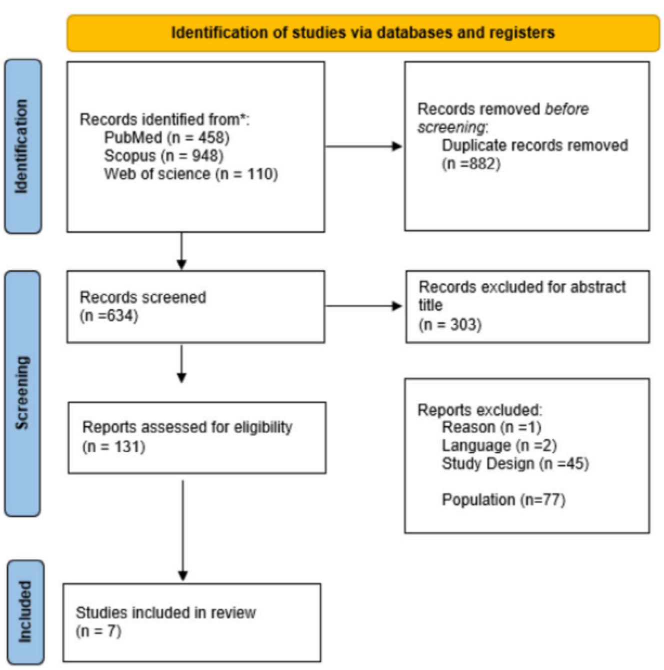

FIGURE 1 PRISMA flow diagram.

The 6 studies included 11,431 adults of both sexes (Tables 2 and 3). The sample size ranged from a minimum of 20 for the RCTs to a maximum of 6054 participants. One RCT was conducted in New Zealand[21] and one in the USA.[22]

Observational studies were conducted one in Australia, one in Korea, and one in China.[23–25] One study used data from the PREVIEW multicentre study cohort, which collects data from Finland, Australia, New Zealand, Bulgaria, and the United Kingdom.[26]

With regard to dietary assessment, three studies used food logs consisting of a different number of days (two used a 3-day log and one a 4-day log)[21,23,26] two studies[24,25] used food frequency questionnaires (FFQs) and one RCT study used weighing of food before and after the meal consumed.[20] The PREVIEW study published by Zhu et al used both the 4-day food diary and a plant-based diet index (PDI) to measure adherence to a plant-based diet, while Jung & Park estimated a plant-based diet index using FFQ (Food Frequency Questionnaire).

Regarding dietary interventions in RCT studies, Wright et al[21] conducted a two-arm parallel superiority prospective study, and compared a low-fat plant-based diet (~7–15% total energy from fat) with the normal diet, both ad libitum. Hall et al,[22] on the other hand, conducted a crossover study in in-patients, comparing a ketogenic diet based on animal products, consisting of ~10% energy from carbohydrates, ~75% from fat and high energy density (~2 kcal g^{-1}), and a plant-based, low-fat diet, with ~10% energy from fat, ~75% from carbohydrates and low energy density (~1 kcal g^{-1}).

3.2 | Plant-based diet, excess body weight, and abdominal obesity

Of the two RCTs, one selected a population that had already overweight or obesity[21] and then assessed BMI and blood cholesterol levels at 6 months; in the other RTC,[22] the selection criterion was not having diabetes type 2, and the study participants had a BMI ranging from 20.6 to 40.8 kg/m^2 (27.8 ± 5.9 kg/m^2).

Both RCTs found a positive effect of the plant-based diet (PBD) on weight loss. Wright et al[21] reported a greater mean BMI reduction at 6 months with the whole food plant-based diet (WFPB) than with the normal diet [4.4 vs. 0.4, difference: 3.9 kg m^{-2} (95% confidence interval [CI] ± 1), $P < 0.0001$]. Hall et al found a slower initial weight loss with a low-food plant-based diet (LFPBD) compared to a low-carbohydrate (LC) diet, but after 2 weeks the weight loss was 1.09 ± 0.32 kg ($P = 0.003$) and the results did not differ significantly from those of the LC diet ($P = 0.15$). The weight change with the LC diet was mostly due to changes in lean mass measured by dual-energy

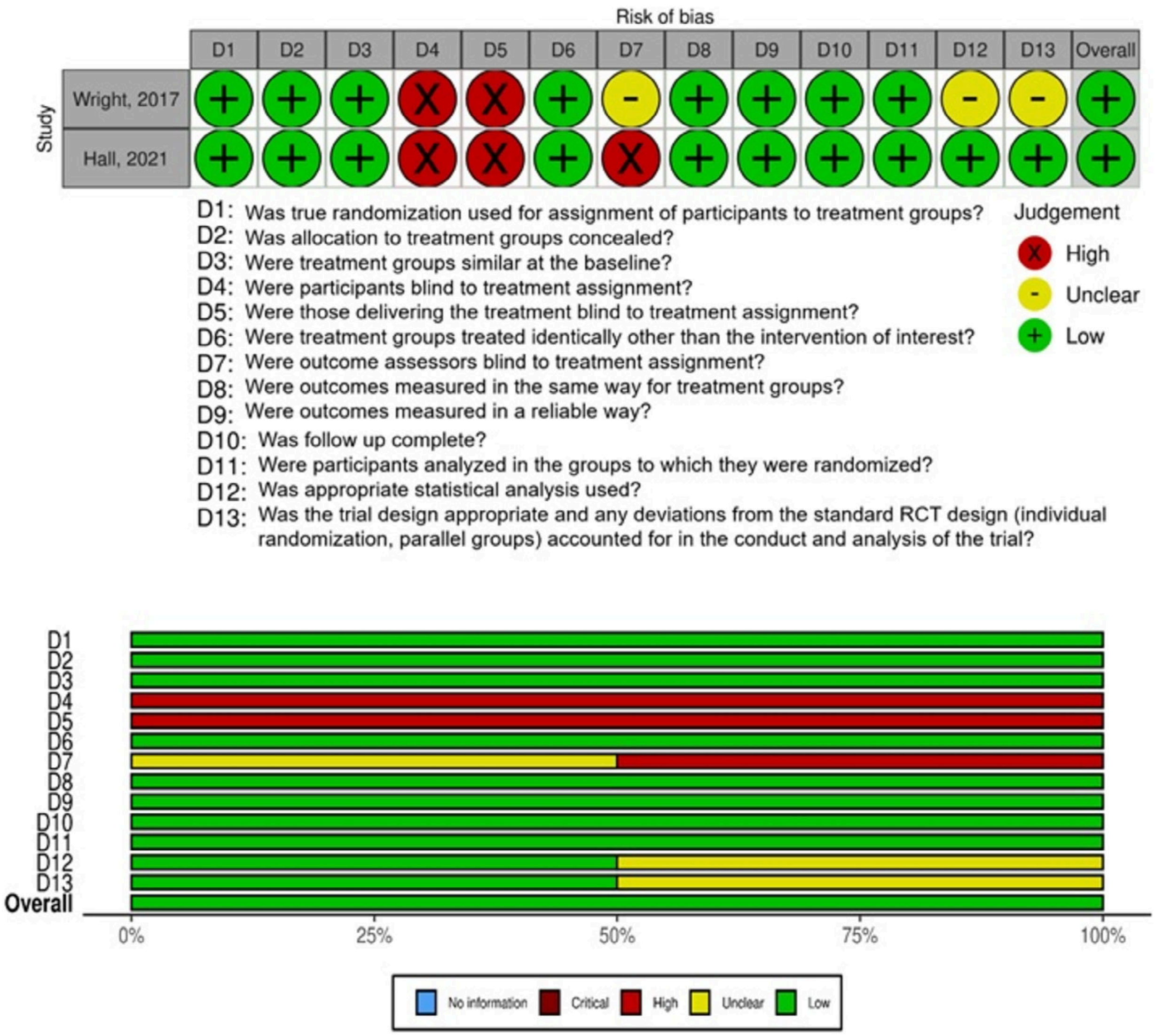

FIGURE 2 Quality assessment of RCT studies.

X-ray absorptiometry (DXA) (−1.61 ± 0.27 kg; P < 0.0001), whereas the LFPB diet did not result in a significant change in lean mass (−0.16 ± 0.27 kg; P = 0.56). Furthermore, in this study fat mass did not change significantly at the end of the LC diet (−0.18 ± 0.19 kg; P = 0.35), whereas the LFPB diet resulted in significant changes in fat mass both after the first week (−0.27 ± 0.12 kg; P = 0.038) and after the second week (−0.67 ± 0.19 kg; P = 0.001). The rate of body fat loss was greater than 35 ± 14 g d-1 (P = 0.019) with the LFPB diet, with an average fat loss rate of 51 ± 10 g d-1 (P < 0.0001) compared to 16 ± 9.7 g d-1 (P = 0.12) with the LC diet.

Two observational studies focused on the risk of overweight and obesity (23; 26), one study on the risk of abdominal obesity,[24] while another study investigated both the risk of overweight and obesity and abdominal obesity.[26] In the study by Zhu et al,[26] the participants at the beginning of the study were all with overweight or obesity and had impaired fasting blood glucose and/or impaired carbohydrate tolerance. Adherence to a PBD was inversely associated with weight regain. In the group considering all participants (n = 688), those with higher PBD adherence regained less weight than those with lower PBD adherence at 52 (1.4 kg vs 2.9 kg; p = <0.05) and 104 weeks (4.7 vs 5.8 kg; p = <0.05). In the group of participants who completed the programme (n = 493), those with higher PBD adherence regained less weight than those with lower PBD adherence at 26 (−0.8 kg vs − 0.0 kg; p = <0.05), 52 (1.2 kg vs 2.5 kg; p = <0.05) and 104 weeks (4.4 kg vs 5.6 kg; p = <0.05). In both groups, however, weight regain at 156 weeks was equal in both the low and high PBD adherence groups. In Wang et al, none of the participants suffered from obesity but the mean BMI was 25.6 kg/m2 (± 2.7). The incidence of obesity at 5-year follow-up was 7.62%. In this cohort study, a significant inverse trend was found between ‘conservative’ dietary pattern (RRQ5VsQ1 = 0.38; 95% CI: 0.15–0.96); p = 0.013), diet quality [RRQ5VsQ1 = 0.23; 95% CI: 0.08–0.66); p = 0.006] and healthy plant-based dietary index (hPDI) (RRQ5VsQ1 = 0.31; 95% CI: 0.12–0.77); p = 0.006) with obesity risk. PDI in general [RRQ5 vs Q1 = 0.56; 95% CI: 0.23–1.33); p = 0.19] also showed a direct correlation with a

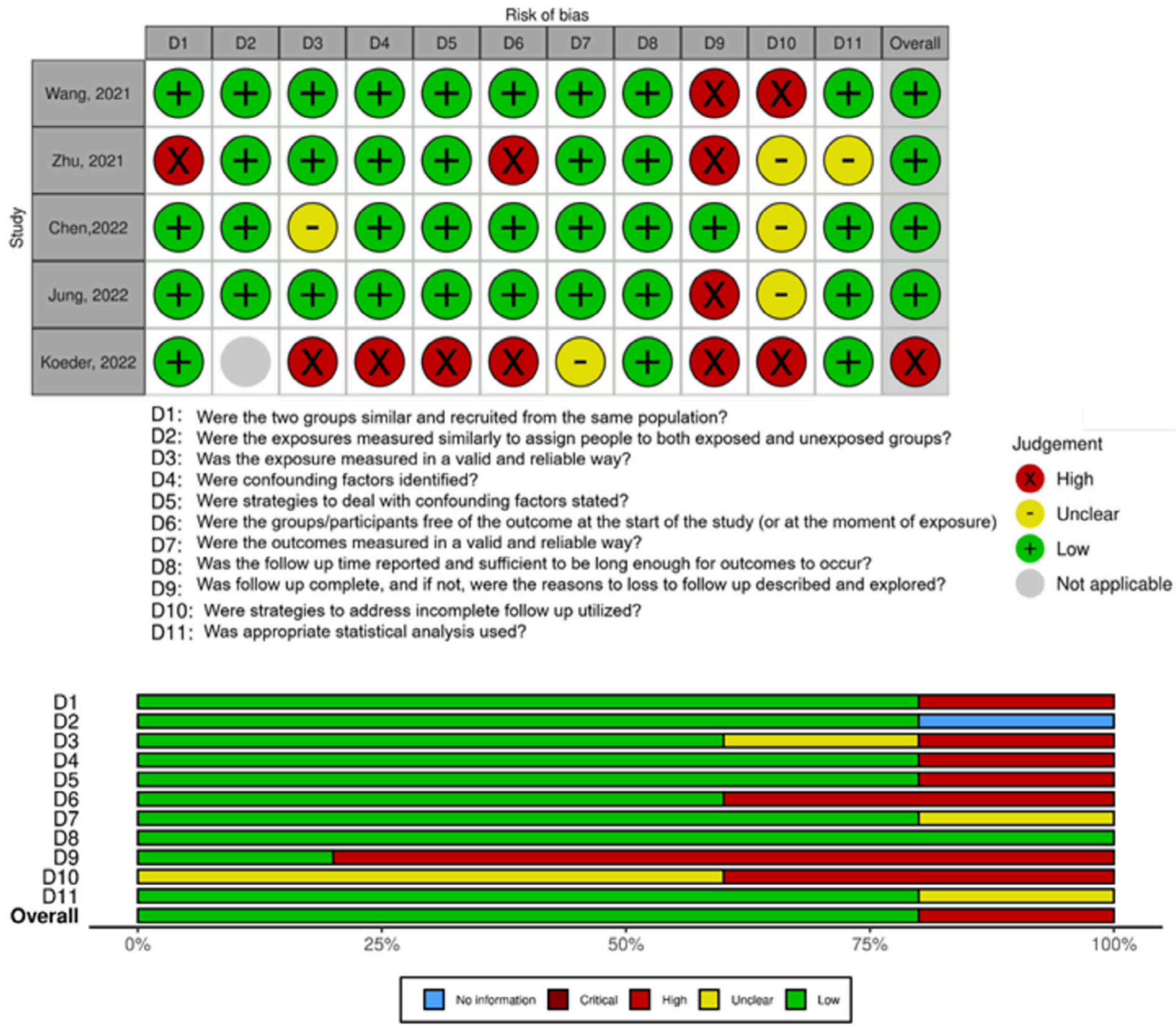

FIGURE 3 Quality assessment of observational studies.

reduced risk of obesity. Regarding DII (dietary inflammatory index), a more anti-inflammatory diet (RRQ2 vs Q1 = 0.58; 95% CI: 0.20–1.68; p = 0.06) was associated with a lower risk of obesity. In contrast, higher quintiles representing a more anti-inflammatory diet were associated with a lower risk of obesity. In contrast, higher quintiles, representing a more pro-inflammatory diet, were associated with a higher risk of obesity. A 'Western' dietary pattern, the so-called Western diet (RRQ5 vs Q1 = 1.13; 95% CI: 0.51–2.53); p = 0.872) and an unhealthy plant-based diet index (unhealthy PDI or uPDI) [RRQ5 vs Q1 = 1.74; 95% CI: 0.74–4.11); p = 0.134] were associated with increased risk of obesity, although not significantly so. After adjustment for other covariates, the association between the 'Western' dietary pattern and obesity risk was stronger. The difference between the healthy plant-based diet (hPDI), and the unhealthy plant-based diet (uPDI) lies in the fact that the former is characterized by a high intake of whole grains, fruits, vegetables, nuts, legumes, tea and coffee, and normally shows inverse associations with adiposity-related inflammatory markers, visceral and subcutaneous abdominal adipose tissue, obesity defined by BMI, weight, waist circumference and waist-to-hip ratio. In contrast, uPDI, characterized by high intake of refined grains, sweets, desserts and sugary drinks, usually shows positive associations with weight gain, metabolic syndrome, high BMI and high waist circumference.[23,24]

In the cohort study of Chen et al,[25] in participants all free of overweight/obesity, 33.4% of participants developed overweight/obesity during the median follow-up period of more than 10 years. The higher PDI (general) score was correlated with a reduced risk of overweight/obesity [HR: 0.71 (95% CI: 0.55–0.93), P-trend < 0.001], and the hPDI score was inversely associated with overweight/obesity [HR: 0.79 (95% CI: 0.62–0.98), P-trend = 0.02]. In Jung et al,[23] participants were all free of abdominal obesity (identified by waist circumference > 90 cm in men and > 85 cm in women according to cut-offs of the Korea Obesity Study Society). During a follow-up of 12.6 years, out of 6054 participants 880 men and 898 women developed abdominal obesity. A high uPDI score was found to be

TABLE 2 Summary of selected RCT studies investigating the association between plant-based diet and overweight/obesity.

Author (year)	Country	Baseline characteristics of subjects	Outcome	Follow-up duration	Dietary evaluation	Covariate	Dietary dietary construct/ regimen/index	Results
Wright, N. et al. (2017)	New Zeland	65 participant (33 interventional arm and 32 control arm) Interventional arm: 67%-woman vs control arm 53% woman. Age interventional arm: 56 ± 9.9 y Vs, control arm 56 ± 9.5 y.	Primary outcome: 6-month variation of BMI and cholesterol Secondary Outcome: changes in medication use, quality of life, cardiovascular risk factors, cardiovascular events, or progression to surgery and transfer to a higher level of care.	12 months	3-day food diary	n/a	whole food low-fat diet (WFPB) 7–15% lipids, the rest carbohydrates, and proteins (~80%) vs normal care, both ad libitum	BMI with WFPB diet - 4.4 vs - 0.4 with normal diet, difference: 3.9 kg m-2 (95% confidence interval [CI] ± 1), $P < 0.0001$). cholesterol reduction with WFPB diet, 0.71 vs 0.26 with normal care, difference: 0.45 mmol l-1 (95% CI ± 0.54), $P = 0.1$). 12 months reassessment: BMI -4.2 (±0.8) kg m-2 with WFPB and total cholesterol −0.55 (±0.54, $P = 0.05$) mmol l-1.
Hall, K.D. et al (2021)	USA	20 participants (crossover) 55% man, age 29.9 ± 6.4 y	Primary outcome: differences in average daily ad libitum energy intake between the low carbohydrates (LC) and plant-based low-fat (LF) diets for the 14 days of each diet. secondary outcome: differences in average daily energy intake for the last 7 days of each diet.	n/a	Monitoring of meals consumed with evaluation of the weight of each food and beverage advanced. Compare with nutrient and energy intake calculated with ProNutra nutrition software.	n/a	Plant-based LF minimally processed (10.3% lipids, 75.2% carbohydrates 14.5% protein) high-glycemic index vs animal-based ketogenic (10% carbohydrates 75.8% lipids, 14.2% protein) minimally processed low-glycemic index diet ad libitum	total weight loss after 2 weeks: LC diet = 1.77 ± 0.32 kg ($P < 0.0001$); LF diet = 1.09 ± 0.32 kg ($P = 0.003$) not significant difference between the two diets ($P = 0.15$). changes in fat-free mass: LC diet = −1.61 ± 0.27 kg; $P < 0.0001$, LF diet = −0.16 ± 0.27 kg; $P = 0.56$

associated with increased risk of abdominal obesity regardless of demographic and lifestyle characteristics, with slightly stronger estimates when the cumulative mean diet was used compared to the baseline diet or the most recent diet (Q5 vs. Q1, uPDIbaseline: HR, 1.70; 95% CI, 1.46 to 1.98; uPDIrecent: HR, 1.52; 95% CI, 1.30 to 1.78; uPDIaverage: HR, 1.76; 95% CI, 1.51 to 2.06). Higher adherence to a diet rich in refined grains, sugars and salted preserved vegetables, characterizing the uPDI, showed here a linear relationship with a 16–24% higher risk of abdominal obesity.

3.3 | Plant-based diet and biochemical and vital parameters

Some of the studies analyzed in this systematic review did not limit themselves to assessing overweight or obesity parameters such as BMI and waist circumference, but also informed biochemical and vital parameters such as cardiocerebrovascular risk or diabetes. In the randomized study by Wright et al,[21] the primary endpoints were BMI and cholesterol. In this RCT, the average reduction in cholesterol at six

TABLE 3 Summary of selected cohort studies investigating the association between plant-based diet and overweight/obesity.

Author (year)	Country	Baseline characteristics of subjects	Outcome	Follow-up duration	Dietary evaluation	Covariate	Dietary intervention	Results
Zhu, R. et al. (2021)	Finland, Australia, New Zealand, Bulgaria, United Kingdom (PREVIEW)	710 participants with overweight (BMI 25–29.9 kg·m − 2) or obesity (BMI ≥ 30 kg·m − 2) and pre-diabetes, 69.2% female, age 57 years [CI46, 63)]; 493 complete the study.	Primary endpoint: T2D incidence[FPG, fasting insulin, HbA1c, HOMA-IR,] Secondary outcomes: (BW), body (FM), (WC), fasting triglycerides, total cholesterol, LDL, (SBP) and (DBP) measured at 8, 26, 52, 104, and 156 weeks.	3 Y	4-day food diary collected at 26, 52, 104, and 156 weeks. Adherence to a plant-based diet (PBD) was assessed by a plant-based diet index (PDI)	Age, gender, ethnicity, smoking habit, and physical activity	Food consumed on average for 4 days expressed in g·day−1 or serving size·day−1 Foods then categorized into 11 food groups.	Δ body weight (95%CI) (kg·year^{-1}) = −0.15 (−0.33, 0.03), P = 0.097. ΔLDL-cholesterol (95%CI) (mmol·L^{-1}·year^{-1}) = −0.02 (−0.04, 0.005), P = 0.119.
Wang, Y.B. et al. (2021)	Australia (NWAHS)	787 participants, 54.1% female, age 58.7 ± 12.9 y	Obesity and overweight	5 y	Dietary Questionnaire for Epidemiological Studies Version 3 (DQES-V3.1)	Age, gender, marital status, smoking habit, alcohol use, physical activity, socioeconomic status	Healthy and unhealthy plant-based diet index (PDI), inflammatory diet index (DII), "Western" diet	Relationship between dietary constructs and obesity risk: Prudent dietary pattern (RRQ5 vs. Q1 = 0.38; 95% CI: 0.15–0.96), healthy PDI (RR = 0.31; 95% CI: 0.12–0.77); overall PDI (RR = 0.56; 95% CI: 0.23–1.33). DII (RR = 1.59; 95% CI: 0.72–3.50); Western dietary pattern (RR = 2.16; 95% CI: 0.76–6.08); unhealthy PDI (RR = 1.94; 95% CI: 0.81–4.66)
Chen, B. et al (2022)	Cina (CHNS)	3795 52.5% women, age of those not developing obesity 46.3 ± 13.4 years, age of those developing obesity 44.0 ± 12.4 years	Obesity and overweight	10.7 y	3-day food diary	Age, energy intake, education level, physical activity, smoking habit, alcohol consumption habit, BMI	plant-based dietary indices [l plant-based diet indice (PDI) and healthy plant-based diet indice (hPDI)]	Association of overweight/obesity risk: PDI score = HR: 0.71 (95% CI: 0.55–0.93), P-trend <0.001]; hPDI score = HR: 0.79 (95% CI: 0.62–0.98), P-trend = 0.02.
Jung, S. e Park, S. (2022)	Corea (KoGES)	6054 participants (54% women) free of abdominal obesity.	Abdominal obesity	9 y.	Semiquantitative (FFQ)	Age, gender, energy intake, education level, physical activity, smoking habit, alcohol consumption habit, BMI	Plant-based diet index (PDI), healthy plant-based index (hPDI), and unhealthy plant-based index (uPDI)	Relationship between dietary constructs and abdominal obesity risk: uPDI score = Q5 vs. Q1: HRbaseline =1.70; 95% CI: 1.46, 1.98). PDI = no significant association.: …

CI = confidence interval; FPG = fasting plasma glucose; HbA1c = glycosylated hemoglobin; HOMA-IR = homeostatic model for assessment of insulin resistance ….

months was greater with the WFPB diet, a non-significant difference compared to the normal diet [0.71 vs. 0.26, difference: 0.45 mmol l-1 (95% CI ± 0.54), P = 0.1], unless drop-outs were excluded [difference: 0.56 mmol l-1 (95% CI ± 0.54), P = 0.05]. At twelve months, the group following the WFPB diet experienced a reduction in total cholesterol of 0.55 mmol l-1 (±0.54, P = 0.05). In the intervention group, glycosylated hemoglobin (HbA1c) recorded a reduction of 5 mmol mol-1 (95% C I ± 3, P < 0.001) at six months.

At twelve months, the intervention mean HbA1c was reduced by 5 mmol mol-1 (range −1 to 15, 95% CI ± 2, P < 0.0001). Among the cohort studies, the secondary outcomes in the study by Zhu et al[26] included fasting blood glucose, fasting insulin, HbA1c, insulin resistance (HOMA-IR), fasting triglycerides, total cholesterol, high-density lipoprotein cholesterol (HDL-c), and low-density lipoprotein cholesterol (LDL-c) at 8, 26, 52, 104, 156 weeks. Adherence to a PBD was inversely associated with increased LDL-c, although after adjustment for weight change the association between PBD and LDL-c was lost. No associations were observed between PBD and other cardiometabolic risk factors after adjustment for covariates, while individual foods were inversely associated with weight regain and cardiometabolic risk factors, independent of weight change. In fact, nut consumption is associated with a decrease in HbA1c, total cholesterol and LDL-c, fruit with a decrease in total cholesterol, LDL-c and diastolic blood pressure, while vegetable consumption is associated with a decrease in triglyceride levels and diastolic blood pressure, and an increase in HDL-c levels. Combined fruit and vegetable consumption is inversely significantly associated with an increase in systolic and diastolic blood pressure and directly correlated with an increase in HDL-c (after adjusting for weight, the correlation with systolic blood pressure is lost).

In Chen et al,[23] during a median follow-up of more than 10 years, of 4775 participants 31.6% had developed hypertension, and of 8211 participants 11.5% had developed type 2 diabetes. The higher hPDI score was associated with a reduced risk of hypertension [HR: 0.63 (95% CI: 0.51–0.79), p-trend <0.001] and type 2 diabetes [HR: 0.79 (95% CI: 0.72–0.87), p-trend <0.001]. The hPDI score was inversely associated with type 2 diabetes [HR: 0.84 (95% CI: 0.75–0.93), p-trend = 0.001]. In the highest quartile of PDI adherence a 21% lower risk of developing diabetes was observed (HR: 0.79, 95% CI: 0.72–0.87, p-trend < 0.001), and in the highest quartile of hPDI adherence a 16% lower risk of developing diabetes (HR: 0.84, 95% CI: 0.75–0.93, p-trend = 0.001).

4 | DISCUSSION

In this systematic review, we have summarized the available randomized controlled trials and cohort studies on the association between the adoption of a plant-based diet modeled on the 'universal' diet theorized by the EAT-Lancet committee,[5] and changes in outcomes related to overweight and/or obesity in adults.

Depending on the purposes of the various studies, those included in the review reported that adherence to a plant-based diet (PBD or PDI) appears to lead to a greater average reduction in BMI compared to a normal diet[21] or a greater reduction in body fat mass with a plant-based diet compared to an animal-based diet (greater body fat loss rate with the plant-based LF diet, compared to the animal-based LC diet).[22]

As far as prevention is concerned, the included studies found a decreased risk of overweight and obesity with adherence to a plant-based diet, especially the so-called healthy type or hPDI. In Wang et al.,[25] PDI showed a direct correlation with a reduced risk of obesity, but hPDI was associated with an increased risk of obesity, although not significantly so. In Jung & Park,[24] the uPDI model (diet high in refined grains, sugars, and salted preserved vegetables) was positively associated with the risk of abdominal obesity in all approaches (p-values < 0.001), and a linear relationship with the risk of abdominal obesity increased by 16–24%. Finally, in the cohort study by Chen et al.,[23] the higher PDI score was correlated with a reduced risk of overweight/obesity, as was the hPDI score inversely associated with overweight/obesity. When weight loss had already occurred, adoption of a plant-based diet appeared to be inversely related to weight regain, with participants showing greater adherence to PBD having regained less weight compared to those with lower adherence to PBD at 26 (-0.8 kg vs -0.0 kg; p = <0.05), 52 (1.2 kg vs 2.5 kg; p = <0.05) and 104 weeks (4.4 kg vs 5.6 kg; p = <0.05).[24] Some of the studies included in this review also found an improvement in metabolic and vital parameters such as glycated hemoglobin, blood cholesterol, and blood pressure following the adoption of a plant-based diet. For example in Wright et al.,[21] a non-significant reduction in cholesterol was found at six and twelve months with the WFPB diet compared to the normal diet. Regarding HbA1c, again in Wright et al.[21] there is a reduction of 5 mmol mol-1 at six months and at twelve months, while in Zhu et al.[26] noted an inverse relationship between nut consumption and HbA1c, which is, however, lost when adjusting for annual weight change. In Chen et al.,[23] a 21% lower risk of developing type 2 diabetes was observed in the highest hPDI quartile and a 16% lower risk of developing diabetes; furthermore, adherence to a higher hPDI was correlated also to a reduced risk of hypertension.

The mechanism behind this body composition effect of plant-based diets may lie in the reduction of the energy density of the food consumed (which usually contains less fat, more water, and more fiber, especially in the hPDI variant), which may lead people to be less hungry and to adhere more to the diet or to a certain dietary balance even in the absence of a low-calorie diet prescription (Figure 4).[21,23]

In the landscape of PDI diets, in fact, the hPDI and uPDI variants differ in micronutrient and mineral content. The difference between a healthy plant-based diet (hPDI) and an unhealthy plant-based diet (uPDI) lies in the fact that the former is characterized by a high intake of whole grains, fruits, vegetables, nuts, legumes, tea, and coffee, which normally shows inverse associations with adiposity-related inflammatory markers, visceral and subcutaneous abdominal adipose tissue, obesity defined by BMI, weight, waist circumference, and waist-to-hip ratio. In contrast, uPDI, characterized by a high intake of refined grains, sweets, desserts, and sugary drinks, usually shows positive associations with weight gain, metabolic syndrome, high BMI, and high waist circumference.[23,25] In Jung & Park, participants belonging to the fifth quintile of the uPDI profile had a lower consumption of potassium, iron, vitamin C, folate, beta-carotene, and dietary fiber

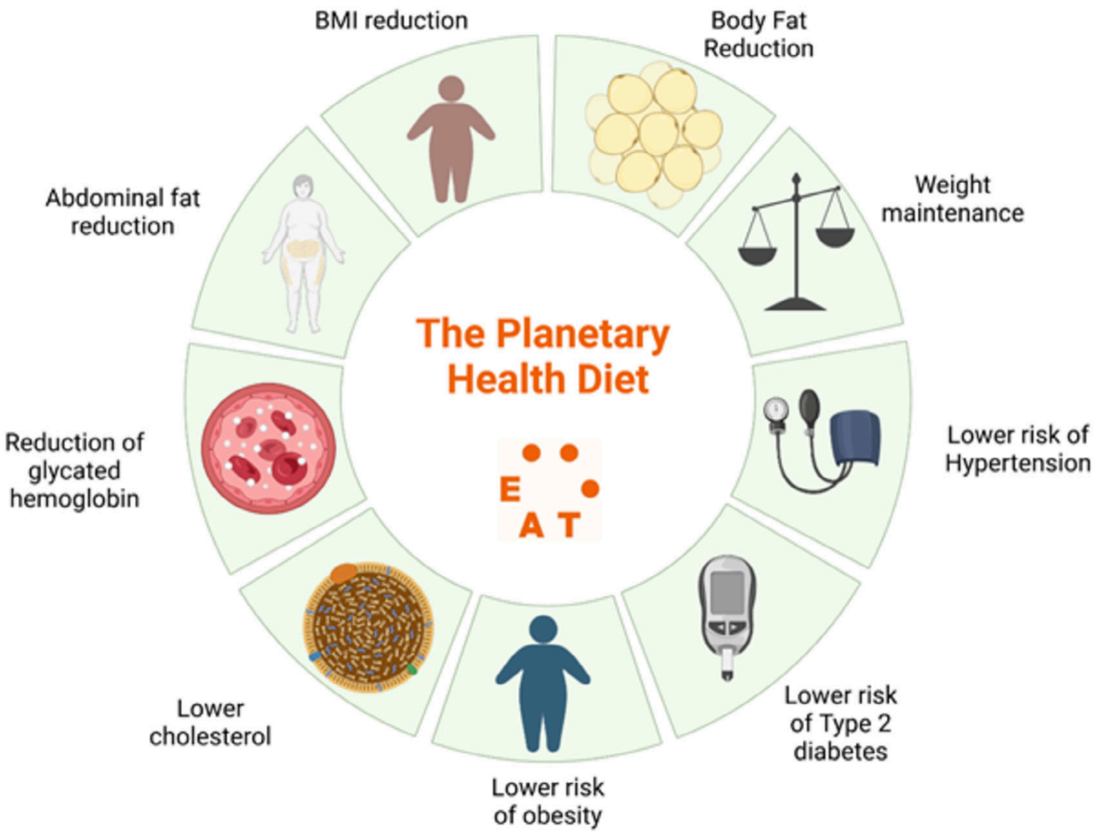

FIGURE 4 Summary of the impact of the planetary health diet on obesity.

than those in the first quintile. According to the authors, some of these elements play a role in the mechanisms of adiposity, e.g. in the deregulation of the iron balance in white adipose tissue in mice by inhibiting adaptive thermogenesis, which we know is also true in humans with regard to brown adipose tissue.[27,28] With regard to vitamin C, here too the authors cite a study in mice to describe the role of this vitamin in inhibiting visceral adipocyte hypertrophy and lowering blood glucose, in part due to suppression expression of genes involved in lipogenesis.[29,30] Indeed, ascorbic acid appears to inhibit adipocyte differentiation and adipogenesis in a dose-dependent manner, and it appears that its treatment may partially reverse the differentiation of preadipocytes into mature adipocytes.[30] Furthermore, dietary folate deficiency could promote increased lipid accumulation and leptin production by adipocytes.[23] In addition to these nutrients, some dietary components such as phytochemicals, probiotics, and prebiotics may contribute to the biological mechanism underlying the relationship between uPDI and obesity, although many aspects are still unclear and strong scientific evidence regarding doses, cut-offs, and mechanisms of action is lacking.[31,32]

With regard to dietary fiber, on the other hand, it has been noted in epidemiological studies that its consumption is usually associated with low body weight and prevention of overweight, effects possibly due to increased satiety or decreased food intake after consumption of fiber-rich foods due to stomach distension, fermentation and changes in gut hormones as possible appetite control mechanisms.[33] However, not all studies agree with the hypothesis that PDI and hPDI, and thus a plant-based diet, would promote satiety and/or lower energy.[33,34] For Clark & Slavin, dietary fiber does not appear to be intrinsically and globally satiating, but satiety may depend on the specific type of fiber (beta-glucans, fiber from lupin, rye bran, whole rye or a high-fiber mixed diet may reduce appetite more frequently than other specific fiber types such as psyllium, wholegrain barley, and wheat bran) or by specific fiber properties (larger particles seem to increase satiety more than smaller particles of the same type of fiber, perhaps because of the longer time required for digestion of the large particles and thus because of the more prolonged glycaemic response), whereas the fact that the fiber is soluble, viscous and/or fermentable seems to have nothing to do with appetite suppression, just as it appears that the energy contribution of short-chain fatty acids or the stimulation of intestinal peptides by short-chain fatty acids may not be effective appetite-reducing mechanisms. Even when high levels of satiety are recorded by visuo-analog scales, this does not always seem to correspond to reduced food and/or energy intake, as food consumption is stimulated by the interaction of several external and internal factors. In the study by Medawar et al., it could not be shown that meals have a different effect on satiety depending on whether they are plant-based or animal-based, whereas the gender of the participants and the taste assessment of the dish (higher for animal-based foods) seem to have a greater impact on satiety.[34]

There is, however, more evidence pointing to dietary fiber as positive on weight, abdominal obesity, and metabolic health through mechanisms that promote lipolysis of adipose tissue; activate the expression of proteins involved in thermogenesis; lower the energy density of the food in which it is contained; decrease plasma ghrelin ('hunger hormone') and increase cholecystokinin, glucagon-peptide-1, peptide YY and leptin secretion; increase chewing time; slow the activity of digestive enzymes and reduce the bioavailability of energy.[35–40] Not all studies agree in attributing changes in body composition in general to a plant-based diet,[41] but as already mentioned, a difference does seem to emerge between healthier (hPDI) and less healthy (uPDI) plant-based patterns, the latter being characterized by a higher consumption of sugary drinks, refined cereals, fruit juices, desserts, and generally highly processed and elaborate products. The hPDI would in fact have a greater relationship with health states than the uPDI, probably due to their content in dietary fiber, antioxidants, potassium, and other minerals, and lower energy density.[41–45]

Despite the associations found, some assessments must be made about the impact this systematic review may have: first of all, the number of included studies is limited. This is because the focus was on RCTs and cohort studies, and on studies on adults. Many studies were in fact done on children, families with children, and in school settings. Another reason why this number is limited is undoubtedly to be found in the plethora of studies citing a plant-based diet without, however, referring to a model similar to the universal diet proposed by the EAT-Lancet, but including models that are avowedly vegetarian, vegan, pescetarian, semi-vegetarian. One of the limitations and problems of heterogeneity of this review is that in the few studies included, there are various inhomogeneities, for example in the methods used for food tracking (food diaries with and without weighing of waste, and FFQs), but above all in the objectives, since some studies focus on prevention, others on regaining or not regaining lost weight, and still others on slimming.

As can be seen from the analysis of the risk of bias (Figures 2 and 3), the selected studies are fairly deficient on a few points in particular. Concerning RCTS, the blindness of the participants and researchers was intrinsically not feasible for the study design. As far as cohort studies are concerned, the participants were often lacking in the outcomes sought, there are high drop-out rates, and thus samples not large enough to make generalization of the results possible (despite the fact that on average the follow-up time was adequate). These are, however, together with problems due to the very nature of food and dietary patterns acting in complex ways on human health, fairly well-known and common limitations in nutrition studies.[45] Moreover, given the small number of studies, we did not distinguish between prospective longitudinal and RCT outcomes. In some longitudinal prospective studies, they explicitly mention HR, RR, in others they do not, so there is some heterogeneity in how the outcome is expressed.

Beyond these, one has to consider the still not fully explored and resolved limitations in considering a 'sustainable' and 'universal' diet. For example, one of the main challenges is the cultural acceptability of the 'EAT-Lancet' diet, which according to the FAO must necessarily be included in the definition of a sustainable diet, which is often assessed according to subjective parameters of researchers. Other aspects not to be underestimated are the method of food consumption, specific considerations for different countries and regions with regard to seasonality, import-export and socio-political peculiarities, and plausibility for different age groups and populations.[46–48] These considerations lead us to another limitation of this systematic review, which is precisely that of having taken as a reference the 'universal' diet proposed by the EAT-Lancet commission: the same commission in fact promotes more than one diet because, for each food category, the article indicates not only the 'reference' quantity, but also a range around it and, for all categories of animal products, this range also includes the value 0. For example, the recommended intake of 'fish' is 28 g/day, with possible ranges from 0 to 100 g/day. Consequently, a vegan diet is considered sustainable and recommendable, as well as somehow belonging to the universe of the 'EAT-Lancet diet'. However, we intentionally excluded studies that did not align with the EAT-Lancet diet's sustainability criteria. These criteria emphasize both specific portion sizes and consumption frequencies, as well as the use of minimally processed foods. While vegan and vegetarian diets are often associated with environmental benefits,[49] it's essential to consider the hidden impact of highly processed meat substitutes.[50] These products, though plant-based, can have a substantial carbon footprint due to their production methods and transportation requirements. Factors like energy consumption, water usage, and packaging materials all contribute to the environmental cost of these alternatives.[49,50] Our aim was to focus on research that closely adheres to the EAT-Lancet model's principles of health and environmental sustainability. The strength of this systematic review was to include only studies with good methodological quality, applying recognized tools to assess as objectively as possible the inclusion or non-inclusion of the selected studies. Moreover, this study is part of a scientific production that is lacking in terms of the effect of the EAT-Lancet diet on health outcomes, but which is certainly fundamental given the urgency and globality of the problems dealt with. It is therefore to be considered a beginning and a wish for a more fruitful and strong scientific production that can guide health workers and world policy-makers in making congruous decisions that simultaneously lead to the solution of health problems for humankind, populations, and the planet.

5 | CONCLUSION

In conclusion, the studies currently available in the literature seem to agree that adherence to a plant-based diet, although not necessarily coded as a vegan or vegetarian diet, is associated with a better weight control, as well as tending to better metabolic and vital parameters. This type of diet has the merit of being both good for human health and good for the climate, as individual foods have a lower climate footprint than those of animal origin. In order to have a low global climate footprint, however, it is not only the choice of food but also the adoption of good food production and consumption practices by people and populations that need to be considered at a cultural and global policy level.

In spite of the positive associations found between the adoption of a plant-based diet and weight and metabolic and health parameters, the studies reported in the literature are still very limited, especially in number, in the heterogeneity of the outcomes, and in their strength, partly due to the intrinsic limits of scientific studies in the nutritional field, but also due to the design of the scientific production and the different plant-based diet definitions. Further intervention and longitudinal studies are therefore needed to confirm these associations, possibly by adopting a well-coded dietary pattern and designing stronger studies with larger populations and adequate follow-up time. Moreover, future research should compare the effects of the EAT-Lancet diet to existing sustainable dietary models, such as vegan and vegetarian diets, to identify potential differences or synergies and areas for improvement.

This review suggests that obesity treatment and nutritional education programs should adopt a more holistic approach by incorporating the principles of sustainability and the core recommendations of the EAT-Lancet diet. This would involve a shift from a sole focus on caloric and nutrient intake to a broader emphasis on dietary quality, health, and environmental impact, promoting the consumption of minimally processed, sustainable foods.

AUTHOR CONTRIBUTIONS

Conceptualization, RDA; methodology, RDA; investigation, SPM, CP, and FM.; writing—original draft preparation, CP, SPM, RDA; writing—review and editing, AF, AL, MP, FS, AB, SB; supervision, RDA.

FINANCIAL DISCLOSURE

Funding: This work was funded by BIBLIOSAN.

ACKNOWLEDGEMENTS

Open access funding provided by BIBLIOSAN.

CONFLICT OF INTEREST

All authors declare no potential conflict of interests.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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How to cite this article: Mambrini SP, Penzavecchia C, Menichetti F, et al. Plant-based and sustainable diet: A systematic review of its impact on obesity. *Obesity Reviews*. 2025;26(6):e13901. doi:10.1111/obr.13901