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REVIEW

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Sustainable diets and risk of overweight and obesity: A systematic review and meta-analysis

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Summary

Sustainable diets are gaining interest as a possible approach to tackle climate change and the global extent of obesity. Yet, the association between sustainable diets and adiposity remains unclear. We performed a systematic review and meta-analysis, calculating summary relative risks and 95% confidence intervals (CI). We pooled maximally adjusted risk estimates, assessed heterogeneity and publication bias, calculated the E-value, and evaluated the risk of bias across the included studies. A total of eight studies were eligible for analysis. Comparing the highest versus the lowest levels of adherence to sustainable diets, the pooled effect estimate was 0.69 (95% CI = 0.62–0.76) for overweight and 0.61 (95% CI = 0.47–0.78) for obesity. These results suggest that sustainable diets may decrease the risk of overweight/obesity and therefore could serve as enablers for improving both public and planetary health. An agreed-upon clear definition of sustainable diets would enhance the comparability of future studies in this area.

KEYWORDS
diets, global health, meta-analysis, obesity, planetary health, sustainability

1 | INTRODUCTION

Overweight and obesity are major public health concerns worldwide. The global prevalence of overweight and obesity has increased substantially over the past few decades and is expected to continue to rise.[1] According to the World Health Organization (WHO), the global prevalence of obesity has almost tripled since 1975. In 2016, there were an estimated 1.9 billion adults with overweight and 650 million with obesity worldwide.[1] In the European region, "overweight and obesity rates have reached epidemic proportions," with almost 60% of the population being either people with overweight or obesity.[2] Furthermore, low- and middle-income countries are experiencing significant increases in the prevalence of overweight and obesity.[3]

Several possible mechanisms lead to overweight and obesity, and dietary habits play an important role. An imbalance between the

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energy demand of the body and an increased energy intake resulting from greater availability and consumption of highly processed and energy-dense food is seen as the main cause.[4] Combined with decreased physical activity levels due to the increasingly sedentary nature of many forms of work, changing modes of transportation, and increasing urbanization,[5] high energy intake can lead to severe adipose tissue accumulation and, thus, to overweight and obesity.[6] Furthermore, currently dominant dietary patterns are harmful to planetary health, contributing to the global syndemic—a confluence of the epidemics of obesity, undernutrition, and climate change.[7] Food production is the single largest cause of global environmental change,[8] causing up to 30% of global anthropogenic greenhouse gas (GHG) emissions[9] while using around 40% of the planet's land[10] and 70% of its fresh water.[11] Moreover, food systems are the main driver of global biodiversity loss.[12] Consequently, innovation and transformation within the food system has the potential to significantly improve sustainability on a large scale.

To address the dual challenges of promoting health and sustainable development, sustainable diets have been suggested as a potential strategy that could play a key role from both a public and planetary health perspective.[8,13,14] Sustainable diets as defined by the Food and Agriculture Organization of the United Nations are "those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."[15] For this article, we follow the definition by Willett et al. of sustainable diets being diets that promote health and well-being while reducing the environmental impact of food production and consumption.[8] Besides mostly plant-based diets such as the Planetary Health Diet (PHD), organic food consumption meets several of the dimensions that characterize sustainable diets.[16] Sustainable diets aim to ensure adequate nutrition of people worldwide while maintaining planetary boundaries and are thereby positively contributing to planetary health.[8,11] Thus, sustainable diets are key for achieving the United Nations' Sustainable Development Goals, particularly Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action).[17]

The relations between sustainable diets and health outcomes have gained increasing relevance in the last few years. For example, a systematic review by Karavasiloglou et al.[18] reported an inverse association between sustainable diets and cancer incidence and cancer-specific mortality.[15] A systematic review and meta-analysis by Bhagavathula et al.[19] showed that organic food consumption is associated with an 11% reduced risk of obesity. Observational studies revealed that sustainable dietary patterns are associated with decreased risk of overweight and/or obesity.[20–22] However, a comprehensive synthesis summarizing the association between sustainable diets and the risk of overweight and obesity is lacking. Therefore, we conducted a comprehensive systematic review and meta-analysis of sustainable diets in relation to the risks of body mass index (BMI)-defined overweight and obesity, carefully assessing potential bias and unmeasured confounding in the underlying studies.

2 | METHODS

2.1 | Search strategy and selection criteria

We conducted a systematic review and meta-analysis adhering to the PRISMA 2020 statement: an updated guideline for reporting systematic reviews (PRISMA).[23] The PRISMA checklist is available in Data S1. Our study protocol was registered a priori with PROSPERO (No. CRD42023408405 accessible at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023408405).

Studies were considered eligible for inclusion if they (1) were observational studies, including cohort, case–control, or cross-sectional studies; (2) were carried out in generally healthy participants; (3) defined sustainable diets as exposure in a reasonable and reproducible way using a sustainability measure and considered BMI-defined overweight/obesity as the primary outcome; (4) provided a relative risk (RR) or odds ratio (OR) and 95% confidence intervals (CI) for the highest versus the lowest levels of sustainable diet/organic food consumption; (5) were published before November 23, 2023; and (6) were written in English language. Studies assessing solely plant-based (such as vegetarian, vegan, raw vegan, and whole food plant-based), traditional diets (e.g., Mediterranean Diet and Paleolithic Diet), or organic diets were only included if they provided some sustainability measures or indices, such as the PHD Index[22] or the Sustainability Diet Index.[22] We furthermore excluded guidelines, editorials, comments, letters, conference abstracts, or news articles. Eligibility criteria were defined prior to conducting the review.

A systematic literature search in the scientific databases PubMed and ISI Web of Science was carried out to retrieve all relevant studies from inception to November 23, 2023. Up to this date, weekly updates provided by both databases were set up and checked regularly. In addition, we manually reviewed the reference lists of matching articles. The search term was predefined (Data S2) and contained sustainable diets and appropriate synonyms, as well as terms related to sustainable behavior (e.g., environmental footprint, GHG emissions, planetary health, or food biodiversity), combined with keywords for overweight and obesity.

2.2 | Data analysis

C. R. and C. J. performed the literature search and examined titles and abstracts before retrieving full text publications that met our inclusion criteria. Two authors (C. R. and C. J.) reviewed the full text articles and made the final choice on inclusion in the meta-analysis. Conflicts over inclusion were resolved by discussion with A. M. S. C. R. extracted the following data from each study and confirmed it with C. J.: author's name, publication year, study design and name, size and age range of study population, geographic region, period of data collection, dietary assessment method, sustainability assessment, method and unit of outcome measurement, risk estimates (RR and OR) with corresponding 95% CIs, and adjustment factors.

The first author of one of the included studies[24] was contacted directly to obtain additional data, and therefore, we were able to compute the 95% CIs ourselves. To calculate high versus low levels of a sustainable diet, we inverted the RRs from one study,[22] proceeding analogously with the corresponding CIs.

We used standard BMI categories as defined by the WHO.[1] BMI is calculated as body weight divided by height in meters squared (kg/m^2) and is classified as follows: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obesity (30.0 kg/m^2).

Outcomes were determined as the natural logarithm of observed RRs (log (RRi)) to calculate the overall estimate. The corresponding sampling variances were specified as the squared standard error. Standard errors were computed as the natural logarithm of the risk ratio subtracted from the upper bound CI (log (ci.ub)-log (RRi)) and the lower bound CI (log (ci.lb)-log (RRi)). We applied a random effects model to our data given high between-study variability. Restricted maximum likelihood estimation was used as an estimator of τ^2. Furthermore, we evaluated Q and I^2 statistics[25] to examine the effects of heterogeneity.

We assessed risk estimates primarily measuring sustainable diets as the exposure variables. In the primary meta-analysis, we included one risk estimate per study, except for one study that assessed men and women separately resulting in two RRs.[26] In all analyses, we chose the most comprehensively adjusted risk estimate available.

To assess the risk of bias in the included studies measuring overweight/obesity as outcome, we used the Cochrane tool Risk of Bias in Non-randomized Studies of Exposures.[27] The following adjustment factors were specified for the assessment of the confounding domain: sex, age, smoking, physical activity, and income/education. The assessment of risk of bias was performed by two researchers (A. M. S. and C. J.). Disagreements between the two authors were resolved by discussion between those authors. The *robvis* tool was used to visualize our risk of bias assessments.[28] The overall certainty of the evidence was evaluated using GRADE.[29]

We assessed publication bias using a funnel plot and trim and fill analysis. Additionally, we performed Egger's regression test and Begg's rank correlation test. To measure each study's impact, influence diagnostics and leave-one-out analysis were evaluated.[30] We calculated the E-value for estimating how strong an unmeasured confounder would need to be to explain away the observed association between exposure and outcome, apart from measured confounding variables.[31]

We performed several sensitivity analyses by study geographic region (Europe, North America, and South America), study design (cross-sectional and cohort), and sample size (<10,000 and ≥10,000 participants). To account for the possibility of overfitting the model because of the inclusion of multiple publications from a single cohort study (NutriNet-Santé), we conducted further analyses in which we included only one estimate at a time. Statistical analyses were carried out using the R program (version: 4.2.3). We used the packages *metafor*, *robumeta*, *EValue*, *dplyr*, and *MetaUtility* to extract risk estimates with 95% CIs. *p*-values <0.05 were considered statistically significant.

3 | RESULTS

3.1 | Study selection and characteristics

Our systematic literature search of electronic databases and hand-searching of reference lists and other publications resulted in 798 potential studies (Figure 1). After removal of duplicates, 795 studies remained for title and abstract screening, of which 18 were full text reviewed. Among those, four studies were excluded due to missing measurements of weight change as outcome, two studies were excluded due to missing ORs, and four studies were excluded because they failed to provide a measure of sustainability. After exclusion, eight studies (four cohort and four cross-sectional studies) were eligible and were included in our systematic review and meta-analysis. The main characteristics of the eight studies included in the systematic review are presented in Table 1. Those studies yielded a total of 438,020 participants at baseline and ultimately 170,923 participants in the analytic sample. Six studies originated from Europe,[22,24,26,32–34] one from North America,[20] and one from South America.[21] Three studies[22,26,32] were based on the same cohort (NutriNet-Santé); however, we integrated all estimates in our main models because the time span of the data collection and the sustainability indices used to assess the exposure of the data collection were distinct in each study.[26,32] Further, sensitivity analyses demonstrated no significant changes of the total risk estimate (Data S3).

3.2 | Dietary assessment methods

The studies included in our meta-analysis utilized different dietary assessment methods, among them questionnaires on food-related lifestyles, food frequency questionnaires, 24 h records (24HR), and information on organic products consumed in the past 12 months. To evaluate sustainability, studies used various indices or scores. The PHD Index[35] assesses adherence to a reference diet proposed by the EAT-Lancet Commission. The Sustainability Diet Index[36] is a score with a maximum of 20 points summed up using four subindices encompassing environmental, nutritional, economic, and sociocultural aspects. Kesse-Guyot et al. utilized an Organic Score ranging between 0 and 32 points across 18 food groups, and Andersen et al.[34] used an overall *organic food score* ranging from 6 to 24 points. Gosling et al.[33] used both a food propensity questionnaire and a 24HR to investigate frequency of organic food consumption across 12 food groups. Pérez-Cueto et al.[37] made use of the food-related lifestyles concept measuring 23 lifestyle dimensions covering identification, preparation,

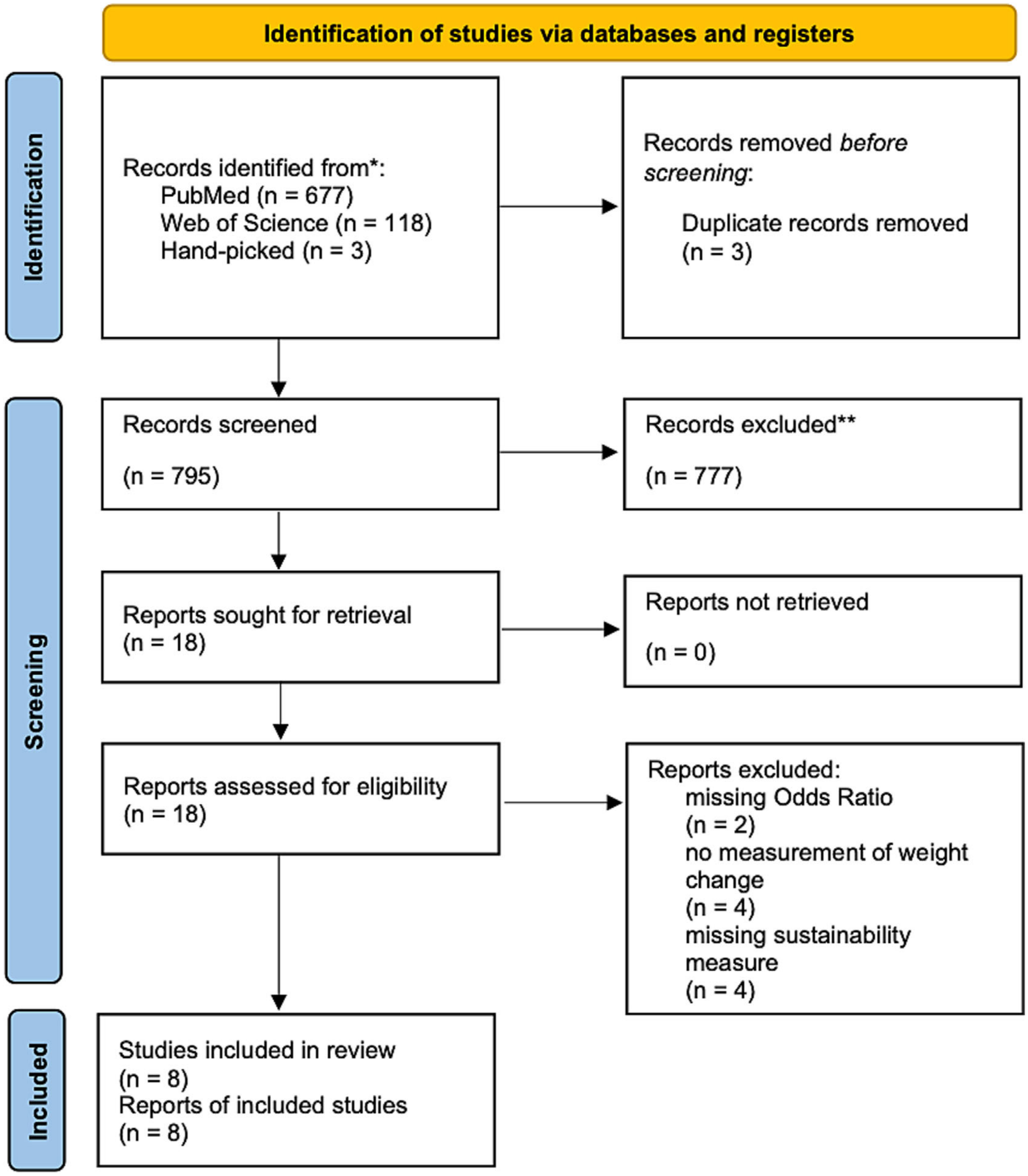

FIGURE 1 Study selection illustrated on PRISMA 2020 flow diagram.[23]

and actual intake of food products, including high versus low organic food consumption.

We aimed to compare the highest versus the lowest levels of sustainable diet in relation to overweight and obesity. All studies used standard BMI categories according to the WHO as outcome variables. The number of adjustment factors varied between 6[22] and 15[33,34] variables per study (Table 1).

3.3 | Sustainable diets and risk of overweight/obesity

Overall, we pooled 15 risk estimates ($N = 6$ for overweight and $N = 9$ for obesity) from eight studies and found a statistically significantly reduced risk of overweight or obesity for high versus low adherence to sustainable diets. The summary risk estimates were RR = 0.69; 95% CI, 0.62–0.76 for overweight and RR = 0.61; 95% CI, 0.47–0.78 for obesity. There was large heterogeneity between studies ($I^2 = 67.3\%$ for overweight; $I^2 = 98.1\%$ for obesity) (Figures 2 and 3).

3.4 | Sensitivity and stratified analyses

Findings of the risk of bias assessment are summarized in Data S4. Two of the eight studies measuring obesity as outcome showed high overall risk of bias due to confounding (domain 1), limitations in measuring dietary habits (domain 2), and handling of missing data (domain 5).

TABLE 1 Study characteristics of four cross-sectional studies and four cohort studies of sustainable diets and the risk of overweight and obesity.

Author, year	Country, study population, total sample size, participants	Analytic sample size	Assessment of exposure	Outcomes	Confounding variables
Cross-sectional studies					
Cacau et al., 2021	Brazil, ELSA-Brasil, 14,515, adult/elderly	14,515	Planetary Health Diet Index	Overweight OR: 0.76 (95% CI: 0.67–0.85) Obesity OR: 0.76 (95% CI: 0.65–0.88)	Age, sex, self-reported race, income, smoking, excessive alcohol consumption, physical activity, diabetes, hypertension, dyslipidemia, energy intake, and dietary changes in the last 6 months
Gosling et al., 2021	France, INCA3, 5855, adult	1679	Self-designed index of organic food consumption	Obesity OR: 0.97 (95% CI: 0.94–0.99)	Age, sex, family income, education level, energy intake, Mediterranean diet adherence, dietary supplements, regimen, processing of food, physical activity, and sedentary lifestyle level
Pérez-Cueto et al., 2010	Belgium, Denmark, Germany, Greece, and Poland, consumer survey, 2437, adult	2437	Online questionnaire on food-related lifestyles	Obesity OR: 0.92 (95% CI: 0.86–0.98)	Age, sex, educational achievement, locality of residence, financial status, and marital status
Jung et al., 2023	USA, NHANES, 34,770, adults	25,262	Sustainable diet index-US (12 indicators with four subindices)	Obesity OR: 0.68 (95% CI: 0.59–0.79)	Age, sex, race, education level, smoking status, alcohol consumption, physical activity level, dietary supplement use, reported total energy intake, and survey cycle
Cohort studies					
Andersen et al., 2022	Denmark, Danish Diet, Cancer and Health cohort, 57,053, adult	43,209	Food frequency questionnaire and a lifestyle questionnaire	Overweight RR: 0.70 (95% CI: 0.60–0.80) Obesity RR: 0.50 (95% CI: 0.50–0.60)	Sex, educational level, BMI, physical activity, alcohol intake, and smoking status
Kesse-Guyot et al., 2013	France, NutriNet-Santé, 54,311, adult	5971 (1080 [men] and 4891 [women] completed mPNNS-GS Data)	Five clusters of organic food consumption	Overweight Men RR: 0.64 (95% CI: 0.53–0.76) Overweight Women RR: 0.58 (95% CI: 0.52–0.65) Obesity Men RR: 0.38 (95% CI: 0.27–0.55) Obesity Women RR: 0.52 (95% CI: 0.43–0.61)	Age, physical activity, education, smoking, energy intake, restrictive diet, and mPNNS-GS

(Continues)

TABLE 1 (Continued)

Author, year	Country, study population, total sample size, participants	Analytic sample size	Assessment of exposure	Outcomes	Confounding variables
Kesse-Guyot et al., 2017	France, NutriNet-Santé, 156,617 (NutriNet-Santé before June 2014), adult	62,224	Computed organic score with a maximum of 32 points	Overweight OR: 0.77 (95% CI 0.68–0.86) Obesity OR: 0.69 (95% CI: 0.58–0.82)	Age, sex, month and year of inclusion, duration of follow-up, occupation, marital status, education, monthly income per unit, dietary supplement use, mPNNS-GS, principal component analysis-extracted dietary pattern scores, energy intake, physical activity, tobacco status, and history of chronic diseases
Seconda et al., 2020	France, NutriNet-Santé, 112,462 (NutriNet-Santé before October 2014), adult	15,626	Sustainable Diet Index (4–20 points conducted of four subindexes [1–5 points] equally contributing and being summed up)	Overweight hazard ratio: 0.67 (95% CI: 0.51–0.88) Obesity hazard ratio: 0.25 (95% CI: 0.16–0.41)	Age, sex, height, physical activity, tobacco status, alcohol consumption, energy without alcohol intake, monthly income per consumption unit, scholarly level, occupational status, marital status, and menopause, and BMI at inclusion

Abbreviations: CI, confidence interval; ELSA-Brazil, Brazilian Longitudinal Study of Adult Health; INCA3, Third Individual and National Studies on Food Consumption; mPNNS-GS, modified French Programme National Nutrition Santé-Guideline Score; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio; RR, risk ratio.

The funnel plot of the obesity risk estimates showed considerable asymmetry indicating potential publication bias, confirmed by Egger's regression test ($z = -6.6636$, $p < 0.0001$) (Data S5). Begg's rank correlation test showed a p of 0.0247 and a Kendall's tau of -0.6111.

Influence diagnostics noted a rather large externally standardized residual (rstudent) of -2.46 for one study[22] (Data S6), which can be explained by the small RR. Leave-one-out diagnostics of the included studies showed no relevant changes in summary risk estimates, showing a range from RR = 0.57 (95% CI = 0.44–0.74) to RR = 0.66 (95% CI = 0.54–0.82) for obesity (Data S6).

The certainty of the evidence was rated as "low," particularly because of risk of bias (see Data S7).

Our sensitivity analysis of unmeasured confounding showed that an unobserved confounder would have to be associated with both sustainable diets and overweight with an RR of at least 2.26 and with obesity with an RR of at least 2.66 to fully explain away the mean RRs of 0.69 and 0.61, respectively. To render the risk estimates statistically nonsignificant, unobserved confounding strength associated with sustainable diets and overweight and obesity with RRs of 1.96 and 1.88 would be necessary to move the upper confidence limits of 0.76 and 0.78, respectively, to include the null.

Stratified subanalyses indicated that the relation of high versus low levels of sustainable diet and weight change was not modified by sample size or different adjustment factors, including adjustments for physical activity, total energy intake, educational level, and social status or income (all p for difference >0.05) (Table 2). Only study design showed a significant p for difference of 0.0007. Comparing studies that assessed primarily organic dietary habits ($N = 5$) with studies assessing nonorganic sustainable diet ($N = 3$) showed no relevant differences in risk estimates (RR 0.64 [95% CI = 0.48–0.86] vs. RR 0.53 [95% CI = 0.27–1.01] with a p for difference of 0.58; Table 2).

We excluded two additional risk estimates given in the study by Cacau et al.,[21] which utilized waist circumference as an additional measure of "increased abdominal obesity" and "substantially increased abdominal obesity," which did not meaningfully alter the results.

4 | DISCUSSION

This systematic review and meta-analysis summarized the existing evidence on the association between sustainable diets and risk of overweight and obesity. Pooling 15 risk estimates from eight studies showed that sustainable diets are associated with a significantly lower risk of overweight and obesity.

The studies included in our meta-analysis assessed plant-based or organic diets which provided additional information on the sustainability of such diets. In general, plant-based diets are more environmentally friendly than meat-rich diets as they are related to less water and land use and less GHG emissions.[38] We furthermore included studies focusing on organic foods as exposure variable because such foods have repeatedly been considered ecologically beneficial and

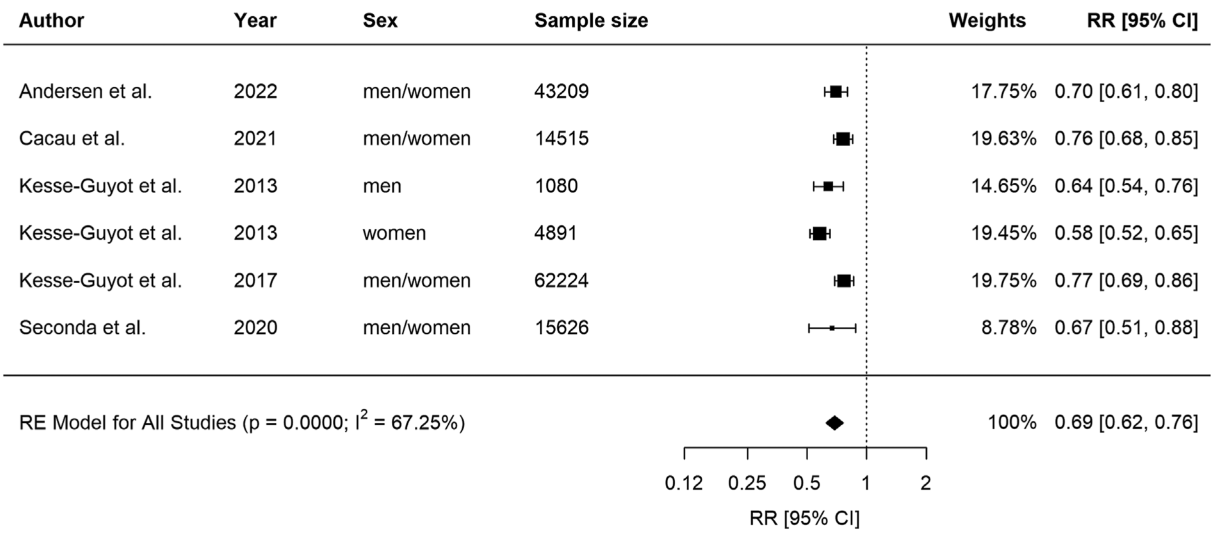

FIGURE 2 Forest plot of random-effects (RE) meta-analysis of adjusted risk estimates of high versus low adherence to sustainable diets in relation to overweight. The black square and the respective line represent the risk estimate and corresponding 95% confidence interval (CI) for each study. The diamond represents the summary relative risk (RR) with the corresponding CI for risk of overweight based on all studies combined. I^2, heterogeneity among studies; *p*, *p*-value (statistical significance).

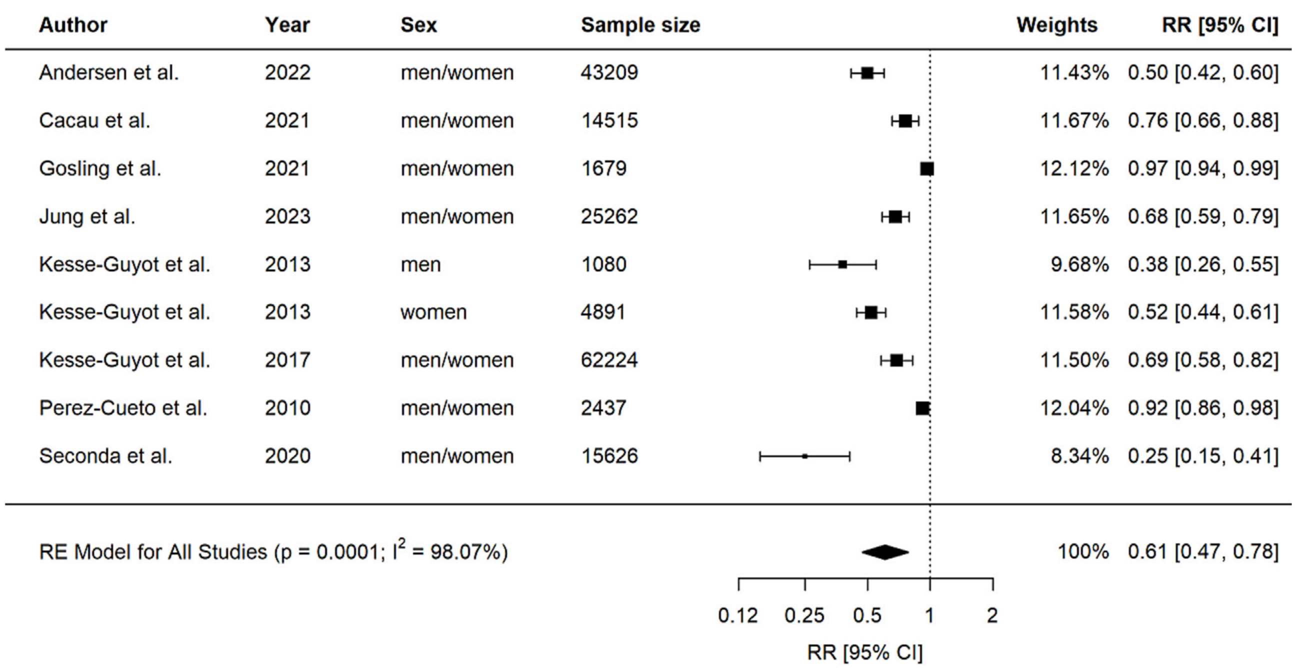

FIGURE 3 Forest plot of random-effects (RE) meta-analysis of adjusted risk estimates of high versus low adherence to sustainable diets in relation to obesity. The black square and the respective line represent the risk estimate and corresponding 95% confidence interval (CI) for each study. The diamond represents the summary relative risk (RR) with the corresponding CI for risk of obesity based on all studies combined. I^2, heterogeneity among studies; *p*, *p*-value (statistical significance).

sustainable,[16,38,39] although they do not always meet all aspects of sustainable diets (especially in terms of monetary costs). However, organic farming practices often prioritize soil health by reducing the use of synthetic pesticides and fertilizers, which can diminish chemical runoff and water pollution.[40–42] By avoiding monoculture and providing habitats for various species, organic food production can help promote biodiversity[43,44] and therefore help maintain ecological balance. Furthermore, studies have shown a potential reduction of GHG emissions associated with organic food production.[45–47] Those are fundamental aspects of sustainability and it therefore seems reasonable to include diets with a high percentage of organic food in our review.

TABLE 2 Stratification criteria, number of included relative risks (RRs), point estimates and 95% confidence intervals (CI) of RRs, difference between included studies, and results of random-effects meta-regression meta-analysis for each subgroup.

Stratification criteria	Number of included RRs	RR (high vs. low sustainable diet)	95% CI	I^2 (%)	$p_{difference}$ (Cochrane's Q test)
Total	15	0.65	0.56, 0.75	95.9	
Overweight	6	0.69	0.62, 0.76	67.4	
Obesity	9	0.61	0.47, 0.78	98.0	0.53
Obesity risk estimates: Subanalyses					
Study geographic region					
Europe	7	0.57	0.41, 0.80	98.7	
North America	1	0.68	0.59, 0.79	NA	
South America	1	0.76	0.66, 0.88	NA	0.00
Study design					
Cohort	5	0.47	0.35, 0.63	88.1	
Cross-sectional	4	0.83	0.71, 0.98	94.5	0.00
Sample size					
>10,000 participants	5	0.56	0.40, 0.79	93.7	
<10,000 participants	4	0.66	0.43, 1.02	99.2	0.53
Adjusted for total energy intake	7	0.58	0.43, 0.80	97.0	
Not adjusted for total energy intake	2	0.68	0.38, 1.24	97.4	0.63
Adjusted for education	8	0.59	0.44, 0.78	98.4	
Not adjusted for education	1	0.76	0.66, 0.88	NA	0.55
Adjusted for social status/income	5	0.68	0.44, 1.04	99.2	
Not adjusted for social status/income	4	0.53	0.43, 0.65	0	0.22
Adjusted for physical activity	8	0.57	0.44, 0.75	96.5	
Not adjusted for physical activity	1	0.92	0.86, 0.98	NA	0.25
Sustainable diets based on organic foods	6	0.64	0.48, 0.86	0.98	
Other sustainable diets	3	0.53	0.27, 1.01	0.96	0.58

To address climate and environmental challenges comprehensively, a combination of sustainable practices, including organic farming, along with policies, technology, and consumer choices is essential.[48]

The benefits of sustainable diets include reduced risk of chronic conditions such as heart disease, diabetes, and certain cancers and show an inverse association with obesity.[38,39,49–51]

Our research provides a basis for emphasizing the beneficial aspects of transforming food systems and diets from a public and planetary health perspective. The biologic mechanisms through which sustainable diets protect against adiposity include their large content of fruits and vegetables and their richness in fiber, which enhances satiety.[52] Furthermore, the nutritional value of sustainable and organic food is possibly higher due to its higher content of vitamins, minerals, antioxidants, and anti-inflammatory compounds, which may prevent weight gain.[53] Additionally, traditional food production exposes animals to considerably higher levels of pesticides, antibiotics, and hormones, which can raise BMI, abdominal fat, and insulin resistance.[53–55] Finally, proponents of a sustainable diet possibly live more health-consciously in general and therefore benefit their overall health, independent of the specific ingredients contained in organically produced foods.[56] While most studies included in our analysis adjusted for lifestyle factors such as physical activity or total energy intake, the results of our stratified subanalyses indicated that the relation of high versus low levels of sustainable diet and weight change was not modified by adjustments for physical activity or total energy intake.

There are some limitations to our study. First, our systematic literature research resulted in a relatively small number of studies included, with European countries being predominantly represented. Also, the number of prospective cohort studies in this area is currently still relatively small, and findings indicated weaker associations between sustainable diets and overweight or obesity in cross-sectional than cohort studies. To confirm our findings, further high-quality research considering all regions of the world equally using different study designs is required.

Second, all studies assessed dietary habits primarily using self-administered questionnaires (e.g., food frequency questionnaires and 24HR) or interviews, instruments potentially susceptible to recall bias, selective reporting, and socially desirable behavior.

Third, the identified studies that assessed obesity showed a moderate to high overall risk of bias, mainly due to potential confounding, known limitations of questionnaire-based dietary assessments as mentioned above, and bias due to missing data without further consideration sensitivity analyses. Given the moderate to high risk of bias, the overall certainty of the evidence according to GRADE was rated as "low."

Fourth, sustainability itself lacks a universally agreed-upon definition. Therefore, every study included utilized a different method to classify sustainable diet, and organic agriculture was assumed to be sustainable, potentially resulting in high between-study heterogeneity. Although organic food consumption seems to be associated with more sustainable diets,[16] the higher monetary costs of organic food is not in line with the Food and Agriculture Organization definition of sustainable diets. Furthermore, the sustainability of organic food can vary depending on factors such as location, crop type, and farming methods. Water and arable land requirements might even be higher than conventional farming methods.[57,58]

Fifth, dietary patterns change over time, so a single measurement of diet at baseline may not fully reflect possible changes of an individual's diet during follow-up or the study period.

Furthermore, our influence diagnostics showed that the Seconda et al. study[22] exerted a modestly disproportionate influence on the pooled obesity risk. That impact was partially explained by the study's comparatively small risk estimate, even though the overall weight of that study was small as indicated by the forest plot.

Our systematic review and meta-analysis has numerous important strengths. We conducted a systematic search in two large databases with a priori defined search terms and extraction of relevant information from included studies. This resulted in a large number of participants included.

To our knowledge, the present study is the first meta-analysis on the association of sustainable diets and the risk of overweight and obesity that utilized the E-value as a criterion for possible undetected confounding. All included studies addressed potential confounding by adjusting their risk estimates for relevant variables. Also, an unobserved confounder needed to be associated both with sustainable diets and the risk of overweight and obesity with a risk ratio of 2.26 and 2.66, respectively, which is rather strong compared with the measured confounding variables. Even if the observed E-values support a true exposure–outcome association, the presence of an unmeasured confounder linked to sustainable diets and overweight and obesity cannot be completely ruled out.[31]

One previous meta-analysis examined the association between organic food consumption and obesity and showed a modest 11% reduction in the risk of obesity. This meta-analysis included one study for which no full-text is available.[59] To calculate a reasonable risk of bias analysis and to obtain valid results, we decided to exclude this study in our analyses. Also, that meta-analysis contained only four obesity risk estimates, whereas we added studies addressing planetary health and sustainability and organic food, resulting in a total of nine obesity risk estimates. Additionally, we did not restrict our outcome to obesity but, rather, included six risk estimates for overweight, which is far more prevalent than obesity. That resulted in a more comprehensive and meaningful analysis of the association between sustainable diets and adiposity risk.

Promoting sustainable and healthy diets is key to combatting the global syndemic or worldwide extent of obesity, undernutrition, and climate change. Not only does the co-occurrence of malnutrition and climate change but also their bidirectional relationship leads to mutual amplification.[7] Specifically, climate change can affect food production and availability, which can impact food choices and dietary patterns through changes in temperature and precipitation patterns. Conversely, obesity and consumption of high-energy, processed foods can cause substantial GHG emissions.[60]

Transition toward more sustainable diets is complex as nutritional behavior heavily depends on food environments, including economic and political factors, resulting in circumstances where unhealthy and nonsustainable foods are often cheaper and more accessible than healthier options.[61] Also, national food-based dietary guidelines widely lack sustainability or planetary health factors, with currently only 17% of the world's population being covered by food-based dietary guidelines that address environmental sustainability.[62] The actual application of sustainable diets is therefore dependent on transformation and improvements in food environments as part of a comprehensive strategy to ensure a healthier and more sustainable future.[7]

In conclusion, the current systematic review and meta-analysis show a decreased risk of overweight and obesity with high adherence to sustainable diets. Our findings make a potentially important contribution to the collective improvement of planetary health and public health through diet. Given the potential cobenefits of sustainable diets for health, climate protection, and sustainable development, more high-quality research is needed to strengthen the evidence, particularly for the PHD. Sustainable food systems are crucial for sustainable development and for fostering human and planetary health.

AUTHOR CONTRIBUTIONS

Christoph Reger, Anja M. Sedlmeier and Carmen Jochem conceived and designed the study and interpreted the data. Christoph Reger, Anja M. Sedlmeier and Carmen Jochem did the statistical analyses and accessed and verified the underlying study data. Christoph Reger wrote the first draft with input from Anja M. Sedlmeier and Carmen Jochem All authors critically revised the manuscript for intellectual content. All authors had full access to the data in the study and had final responsibility for the decision to submit for publication.

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CONFLICT OF INTEREST STATEMENT

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY STATEMENT

The corresponding author (C. J.) can provide relevant meta-level data, protocol, and analytical code upon request. All requests will need to provide a methodologically sound justification. Requests can be made indefinitely starting from the publication of this article. However, it is important to note that individual participant level data or study-level data from any specific study included in the meta-analysis are not accessible through this request.

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REFERENCES

1. World Health Organization. *Obesity and Overweight*. WHO; 2021.
2. World Health Organization, Regional Office for, E. *WHO European Regional Obesity Report 2022*. World Health Organization. Regional Office for Europe; 2022.
3. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384(9945):766-781. doi:10.1016/S0140-6736(14)60460-8
4. Lin X, Li H. Obesity: epidemiology, pathophysiology, and therapeutics. *Front Endocrinol (Lausanne)*. 2021;12:706978. doi:10.3389/fendo.2021.706978
5. World Health Organization. *Global Status Report on Physical Activity 2022*. WHO; 2022.
6. Rutkowski JM, Davis KE, Scherer PE. Mechanisms of obesity and related pathologies: the macro- and microcirculation of adipose tissue. *FEBS j*. 2009;276(20):5738-5746. doi:10.1111/j.1742-4658.2009.07303.x
7. Swinburn BA, Kraak VI, Allender S, et al. The global syndemic of obesity, undernutrition, and climate change: the Lancet Commission report. *Lancet*. 2019;393(10173):791-846. doi:10.1016/S0140-6736(18)32822-8
8. Willett W, Rockström J, Loken B, et al. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet*. 2019;393(10170):447-492. doi:10.1016/S0140-6736(18)31788-4
9. Vermeulen SJ, Campbell BM, Ingram JS. Climate change and food systems. *Annu Rev Env Resour*. 2012;37(1):195-222. doi:10.1146/annurev-environ-020411-130608
10. Foley JA, DeFries R, Asner GP, et al. Global consequences of land use. *Science*. 2005;309(5734):570-574. doi:10.1126/science.1111772
11. Steffen W, Richardson K, Rockström J, et al. Planetary boundaries: guiding human development on a changing planet. *Science*. 2015;347(6223):1259855. doi:10.1126/science.1259855
12. Benton TG et al. *Food System Impacts on Biodiversity Loss. Three Levers for Food System Transformation in Support of Nature*. Chatham House; 2021:02-03.
13. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet Health*. 2018;2(10):e451-e461. doi:10.1016/S2542-5196(18)30206-7
14. Laine JE, Huybrechts I, Gunter MJ, et al. Co-benefits from sustainable dietary shifts for population and environmental health: an assessment from a large European cohort study. *Lancet Planetary Health*. 2021;5(11):e786-e796. doi:10.1016/S2542-5196(21)00250-3
15. Burlingame B, Dernini S. Sustainable diets and biodiversity: directions and solutions for policy, research and action. In: *International Scientific Symposium, Biodiversity and Sustainable Diets United Against Hunger, FAO Headquarters, Rome, Italy, 3-5 November 2010*; 2012.
16. Baudry J, Pointereau P, Seconda L, et al. Improvement of diet sustainability with increased level of organic food in the diet: findings from the BioNutriNet cohort. *Am J Clin Nutr*. 2019;109(4):1173-1188. doi:10.1093/ajcn/nqy361
17. UN General Assembly. *Transforming Our World: the 2030 Agenda for Sustainable Development*. UN General Assembly; 2015.
18. Karavasiloglou N, Pannen ST, Jochem C, Kuhn T, Rohrmann S. Sustainable diets and cancer: a systematic review. *Curr Nutr Rep*. 2022;11(4):742-752. doi:10.1007/s13668-022-00442-z
19. Bhagavathula AS, Vidyasagar K, Khubchandani J. Organic food consumption and risk of obesity: a systematic review and meta-analysis. *Healthcare (Basel)*. 2022;10(2):231. doi:10.3390/healthcare10020231
20. Jung S, Young HA, Simmens SJ, Braffett BH, Ogden CL. The cross-sectional association between a sustainable diet index and obesity among US adults. *Obesity (Silver Spring)*. 2023;31(7):1962-1971. doi:10.1002/oby.23783
21. Cacau LT, Benseñor IM, Goulart AC, et al. Adherence to the planetary health diet index and obesity indicators in the Brazilian longitudinal study of adult health (ELSA-Brasil). *Nutrients*. 2021;13(11):3691. doi:10.3390/nu13113691
22. Seconda L, Egnell M, Julia C, et al. Association between sustainable dietary patterns and body weight, overweight, and obesity risk in the NutriNet-Santé prospective cohort. *Am J Clin Nutr*. 2020;112(1):138-149. doi:10.1093/ajcn/nqz259
23. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi:10.1136/bmj.n71
24. Gosling CJ, Goncalves A, Ehrminger M, Valliant R. Association of organic food consumption with obesity in a nationally representative sample. *Br J Nutr*. 2021;125(6):703-711. doi:10.1017/S0007114520003189
25. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539-1558. doi:10.1002/sim.1186
26. Kesse-Guyot E, Péneau S, Méjean C, et al. Profiles of organic food consumers in a large sample of French adults: results from the Nutrinet-Santé cohort study. *PLoS ONE*. 2013;8(10):e76998. doi:10.1371/journal.pone.0076998
27. Higgins J, Rooney A, Taylor K, et al. *Risk of Bias in Non-Randomized Studies—of Exposure (ROBINS-E)*. ROBINS-E Development Group; 2022.
28. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): an R package and shiny web app for visualizing risk-of-bias assessments. *Research Synthesis Methods*. 2020. n/a(n/a);12(1):55-61. doi:10.1002/jrsm.1411
29. Guyatt G, Oxman AD, Akl EA, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol*. 2011;64(4):383-394. doi:10.1016/j.jclinepi.2010.04.026
30. Viechtbauer W, Cheung MW. Outlier and influence diagnostics for meta-analysis. *Res Synth Methods*. 2010;1(2):112-125. doi:10.1002/jrsm.11
31. VanderWeele TJ, Ding P. Sensitivity analysis in observational research: introducing the E-value. *Ann Intern Med*. 2017;167(4):268-274. doi:10.7326/M16-2607
32. Kesse-Guyot E, Baudry J, Assmann KE, Galan P, Hercberg S, Lairon D. Prospective association between consumption frequency of organic food and body weight change, risk of overweight or obesity: results from the NutriNet-Santé Study. *Br J Nutr*. 2017;117(2):325-334. doi:10.1017/S0007114517000058

33. Pérez-Cueto FJ et al. Food-related lifestyles and their association to obesity in five European countries. *Appetite*. 2010;54(1):156-162. doi:10.1016/j.appet.2009.10.001
34. Andersen JLM, Frederiksen K, Raaschou-Nielsen O, et al. Organic food consumption is associated with a healthy lifestyle, socio-demographics and dietary habits: a cross-sectional study based on the Danish Diet, Cancer and Health cohort. *Public Health Nutr*. 2022;25(6):1543-1551. doi:10.1017/S1368980021001270
35. Cacau LT, de Carli E, de Carvalho AM, et al. Development and validation of an index based on EAT-Lancet recommendations: the Planetary Health Diet Index. *Nutrients*. 2021;13(5):1698. doi:10.3390/nu13051698
36. Seconda L, Baudry J, Pointereau P, et al. Development and validation of an individual sustainable diet index in the NutriNet-Santé study cohort. *Br J Nutr*. 2019;121(10):1166-1177. doi:10.1017/S0007114519000369
37. Scholderer J, Brunsø K, Bredahl L, Grunert KG. Cross-cultural validity of the food-related lifestyles instrument (FRL) within Western Europe. *Appetite*. 2004;42(2):197-211. doi:10.1016/j.appet.2003.11.005
38. Gibbs J, Cappuccio FP. Plant-based dietary patterns for human and planetary health. *Nutrients*. 2022;14(8):1614. doi:10.3390/nu14081614
39. Barnard ND, Levin SM, Yokoyama Y. A systematic review and meta-analysis of changes in body weight in clinical trials of vegetarian diets. *J Acad Nutr Diet*. 2015;115(6):954-969. doi:10.1016/j.jand.2014.11.016
40. Haering A et al. Benefits of organic farming for society. In: *European Conference-Organic Food and Farming*. Citeseer; 2001.
41. Nejadkoorki F. *Environmental Benefits of Organic Farming*. IntechOpen.; 2012.
42. Parizad S, Bera S. The effect of organic farming on water reusability, sustainable ecosystem, and food toxicity. *Environ Sci Pollut Res Int*. 2021;30(28):71665-71676. doi:10.1007/s11356-021-15258-7
43. Bengtsson J, Ahnström J, Weibull A-C. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *J Appl Ecol*. 2005;42(2):261-269. doi:10.1111/j.1365-2664.2005.01005.x
44. Rahmann G. Biodiversity and organic farming: what do we know? *Landbauforschung Volkenrode*. 2011;61:189-208.
45. El N, Scialabba N, Ller-Lindenlauf M. Organic agriculture and climate change. *Renew Agricult Food Syst*. 2010;25(2):158-169. doi:10.1017/S1742170510000116
46. Squalli J, Adamkiewicz G. Organic farming and greenhouse gas emissions: a longitudinal U.S. state-level study. *J Clean Prod*. 2018;192:30-42. doi:10.1016/j.jclepro.2018.04.160
47. Skinner C, Gattinger A, Krauss M, et al. The impact of long-term organic farming on soil-derived greenhouse gas emissions. *Sci Rep*. 2019;9(1):1702. doi:10.1038/s41598-018-38207-w
48. Muller A, Schader C, el-Hage Scialabba N, et al. Strategies for feeding the world more sustainably with organic agriculture. *Nat Commun*. 2017;8(1):1290. doi:10.1038/s41467-017-01410-w
49. Baudry J, Méjean C, Péneau S, et al. Health and dietary traits of organic food consumers: results from the NutriNet-Santé study. *Br J Nutr*. 2015;114(12):2064-2073. doi:10.1017/S0007114515003761
50. Neufingerl N, Eilander A. Nutrient intake and status in adults consuming plant-based diets compared to meat-eaters: a systematic review. *Nutrients*. 2021;14(1):29. doi:10.3390/nu14010029
51. Dinu M, Abbate R, Gensini GF, Casini A, Sofi F. Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies. *Crit Rev Food Sci Nutr*. 2017;57(17):3640-3649. doi:10.1080/10408398.2016.1138447
52. Hervik AK, Svihus B. The role of fiber in energy balance. *J Nutr Metab*. 2019;2019:4983657.
53. Barański M, Średnicka-Tober D, Volakakis N, et al. Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. *Br J Nutr*. 2014;112(5):794-811. doi:10.1017/S0007114514001366
54. Dangour AD, Lock K, Hayter A, Aikenhead A, Allen E, Uauy R. Nutrition-related health effects of organic foods: a systematic review. *Am J Clin Nutr*. 2010;92(1):203-210. doi:10.3945/ajcn.2010.29269
55. Aleisha Fetters K. *Will Going Organic Help You Lose Weight?* U.S. News; 2015.
56. Eisinger-Watzl M, Wittig F, Heuer T, Hoffmann I. Customers purchasing organic food-do they live healthier? Results of the German National Nutrition Survey II. *Eur J Nutr Food Safety*. 2015;5(1):59-71. doi:10.9734/EJNFS/2015/12734
57. Rasche L, Steinhauser J. How will an increase in organic agricultural area affect land use in Germany? *Organic Agricult*. 2022;12(4):513-530. doi:10.1007/s13165-022-00405-2
58. Treu H, Nordborg M, Cederberg C, et al. Carbon footprints and land use of conventional and organic diets in Germany. *J Clean Prod*. 2017;161:127-142. doi:10.1016/j.jclepro.2017.05.041
59. Park Y-M, O'Brien K, Sandler D. Association between organic food consumption and risk of obesity in women. *Current Developments in Nutrition*. 2020;4(Supplement_2):nzaa063_065. doi:10.1093/cdn/nzaa063_065
60. Koch CA, Sharda P, Patel J, Gubbi S, Bansal R, Bartel MJ. Climate change and obesity. *Horm Metab Res*. 2021;53(9):575-587. doi:10.1055/a-1533-2861
61. Husband A. Climate change and the role of food price in determining obesity risk. *Am J Public Health*. 2013;103(1):e2. doi:10.2105/AJPH.2012.301084
62. James-Martin G, Baird DL, Hendrie GA, et al. Environmental sustainability in national food-based dietary guidelines: a global review. *Lancet Planetary Health*. 2022;6(12):e977-e986. doi:10.1016/S2542-5196(22)00246-7

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