Investigating intervention components and their effectiveness in promoting environmentally sustainable diets: a systematic review

Noor M Wadi, Kenza Cheikh, Yan Wah Keung, Rosemary Green

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Central London Community Healthcare NHS Trust, London, UK (N M Wadi RD MSc, K Cheikh RD BSc)**; Department of Dietetics, Sheffield Hallam University, Sheffield, UK** (Y W Keung MSc)**; Centre on Climate Change and Planetary Health, Department of Population Health, London School of Hygiene & Tropical Medicine, London, UK** (R Green PhD)

Correspondence to: Miss Noor M Wadi, Central London Community Healthcare NHS Trust, London NW8 8EG, UK **noormajdiwadi@gmail.com**

Global food systems contribute 30% of global greenhouse gas emissions, threatening the global temperature targets of the Paris Agreement. Diets in high-income countries exceed the recommendations for animal-based foods, whereas consumption of fruits and vegetables is below recommendations. Shifting to a more plant-based diet can reduce up to 30% of greenhouse gas emissions from diet and also reduce risk of chronic disease. Interventions addressing sustainable dietary behaviour, defined by a shift in dietary patterns and food-waste practices, could therefore improve population and planetary health, but knowledge of the interventions that are likely to be most effective in changing sustainable dietary behaviour is so far limited. This systematic review aimed to investigate, classify, and assess the effectiveness of interventions that promote environmentally sustainable diets in high-income countries. We searched MEDLINE, Embase, PsycINFO, and Cumulative Index to Nursing and Allied Health Literature for randomised controlled trials and quasi-experimental trials published from inception until June 16, 2022, evaluating the effectiveness of any intervention promoting environmentally sustainable dietary behaviour. Studies were eligible for inclusion if they included adults and children from high-income countries (as defined by the World Bank classification) and used individual-level behaviour change interventions. Online choice experiments and studies reporting results on only change in fruit and vegetable consumption were excluded. Interventions were classified using the nine intervention functions of the behaviour change wheel. Data were extracted on number of participants, intervention characteristics, diet change (eg, meat consumption and fruit and vegetable intake), food waste, greenhouse gas emissions, and health outcomes. 13 studies were identified and included in the systematic review. Articles were from six different countries (ie, Canada, the USA, Germany, the UK, the Netherlands, Italy). Six of the nine intervention functions of the behaviour change wheel were used. Interventions using education had the most robust evidence base, whereas interventions using persuasion had the strongest effect on reducing meat consumption. Overall, interventions using education in combination with other factors were most successful. Five studies had high risk of bias, five had some concerns of bias, and three had low risk of bias. This systematic review provides insight into the effectiveness of behavioural interventions to meet health and climate change goals through promotion of environmentally sustainable diets. Evidence supports the use of multicomponent interventions through education, persuasion, and environmental restructuring to provide opportunity for change. Little high-quality research was available, and more robustly designed intervention studies are needed to inform future guidelines and policies.

Introduction

Food production and food waste are major contributors to climate change, contributing up to 30% of greenhouse gas emissions,[1] and approximately a third of food produced each year is wasted (ie, not consumed),[2] equating to 8–10% of greenhouse gas.[3] The increasing greenhouse gas emissions threaten the global temperature targets of the Paris Agreement[4] and pose substantial risks for both planetary and human health through exposure to poor air quality, reduced agricultural yields, declining food quality, and risks to food safety.

Evidence from lifecycle assessments shows that animal-based foods, particularly red meat, have larger environmental impacts than plant-based foods,[1,5] such that the total dietary greenhouse gas emissions of meat eaters are about twice those of vegans.[6] Current intake of animal-based foods in most high-income countries exceeds dietary recommendations, whereas consumption of fruits and vegetables tends to be below recommendations.[7] Additionally, research shows an association between poor-quality diets and diet-related disease, such as cardiovascular disease,[8] obesity,[7] diabetes,[9] and some cancers.[8,10,11] Ultimately, the risk that our eating and food-waste habits pose for both human and planetary health warrant an urgent shift in dietary patterns.

The EAT–*Lancet* Commission report[1] defined dietary guidelines to promote both human and environmental health, with diets consisting of mainly vegetables, fruits, whole grains, legumes, nuts, and unsaturated oils with only a small amount of fish and poultry and no or very little red meat. Sustainable food-waste practices involve a reduction in cropland wasted compared with the average global dietary patterns, which consist of a low intake of the foods defined in the EAT–*Lancet* dietary guidelines. Several analyses have shown the potential to significantly reduce national emissions from diets by 17–30% through shifting population dietary habits to meet WHO dietary guidelines or the UK's Eatwell Guide.[12] Similarly, Harwatt and colleagues[13] reported that replacing beef with lentils would contribute 46–75% of the total amount required to meet the 2020 greenhouse gas target for the USA. These analyses show that a shift in consumption patterns might have a notable effect on

greenhouse gas emissions, and these patterns are an untapped opportunity to help to meet international climate targets.[14,15]

Substantial acceleration of the overall reduction in meat consumption in high-income countries is required to meet climate targets.[16] A quarter of UK meat eaters report that they would like to cut down on meat consumption;[17,18] however, barriers to change make it difficult to encourage population-wide diet change.[19] Our food choices are a complex interaction between the social, physical, and individual environment. For instance, meat-eating behaviours are strongly embedded in sociocultural events and activities.[20] Additionally, beliefs about the health benefits of meat consumption;[21] an absence of knowledge about the environmental effects of our diets; affordability and accessibility of sustainable food products and practices; and difficulty obtaining, storing, and cooking the necessary foods for a healthy plant-based diet have been reported as barriers to uptake of sustainable diets.[20,22]

Consumer dietary behaviour change has become a key area of research; however, few studies have systematically reviewed the effectiveness of interventions in promoting sustainable diets. Blackford[23] conducted a systematic review focused only on nudging interventions to promote sustainable consumption. Abrahamse[24] reported on various behaviour change interventions for promoting sustainable diets, such as nudging, changes to the food environment, carbon and environmental labels on food packaging, provision of information, visual prompts, and social norms; however, the report was a non-systematic mini-review and therefore did not comprehensively search many sources of evidence. A 2022 systematic review[25] evaluated interventions between 2001 and 2019 addressing a reduction in meat consumption but mainly measured the effects on intentions, attitudes, or acceptance of meat consumption. As yet, no systematic review has explored the effectiveness of multiple intervention types on a change in overall sustainable dietary habits, food waste, and greenhouse gas emissions with the use of an established behaviour change framework.

This systematic review aims to investigate and classify all interventions that promote environmentally sustainable diets in high-income countries through application of the behaviour change wheel. The main research question is what types of interventions are effective at eliciting a change in individual sustainable dietary behaviour?

See Online for appendix

The COM-B model of behaviour change identifies three essential conditions that are required for behaviour change interventions to be effective in changing behaviour: capability, opportunity, and motivation. Within the three components are further subdivisions that capture the distinctions in each. The behaviour change wheel encompasses the COM-B model at its centre, surrounded by nine intervention functions aimed at addressing deficits in these conditions, along with seven policy categories that could enable those interventions at the policy level. Table 1 shows the links between the components of the COM-B model of behaviour and the intervention functions. This systematic review categorises the interventions identified into the nine intervention functions (figure 1) and evaluates their effectiveness in promoting sustainable dietary behaviour change.

Sustainable dietary behaviour change is complex, involving many interacting components, making them difficult to replicate in research, implement in real-life scenarios, and synthesise in systematic literature reviews.[38] Thus, to understand the most effective way to elicit sustainable dietary behaviour change, this systematic review will identify all current interventions available and use the behaviour change wheel as a systematic classification framework to categorise the intervention content into the intervention functions presented. By doing so, we will be able to identify which intervention functions are most effective in changing the target behaviour, inform future research, and guide the selection of interventions and policies to promote sustainable dietary behaviour change at the local and national level. The behaviour change wheel is a practical guide to organising and evaluating behaviour change interventions and is a reliable method to classify the components of health strategies, such as the UK tobacco strategy[39] and the 2006 National Institute for Health and Clinical Excellence obesity guidance.[40]

Methods

Search strategy and selection criteria

We searched MEDLINE, Embase, PsycINFO, and Cumulative Index to Nursing and Allied Health Literature for articles published from inception until June 16, 2022. No time or journal restrictions were placed on publications. These four databases cover the largest number of records, studies with behavioural interventions, and the social sciences literature; therefore, we expected these databases to include all relevant literature due to breadth of subject focus. Three blocks of search terms were included, focusing on sustainability, health, and study design. Individual search terms included "sustainable consumption" or "meat reduction" or "plant-based" or "health promotion" or "consumer behaviour" (for the detailed search strategy see appendix pp 1–5). We also searched grey literature sources.

To identify eligible studies, we screened titles and abstracts. All studies including adults and children in high-income countries, defined by the World Bank classification,[41] were eligible for inclusion. Where studies included data for other populations, only data for those in high-income countries were included. The use of this large age range was due to the considerable room for dietary change across the lifespan. The population was restricted to high-income countries, because these countries disproportionately contribute to climate change

	Country	Participants, n	Mean age, years (SD)	Intervention	Control	Duration	Outcomes	Intervention function
Randomised controlled trials								
Amiot et al (2018)[26]	Canada	32 (16 in the intervention group and 16 in the control group)	23·5 (3·2)	Multicomponent intervention, including one-on-one information session involving a PowerPoint presentation on emerging social norms and negative effects of meat eating, mind attribution task, and two videos by People for the Ethical Treatment of Animals about the negative treatment of meat-animals; participants received text-message reminders with information and tips or links to recipes	No intervention	4 weeks	Meat consumption (g)	Education, training, persuasion, and modelling
Bianchi et al (2022)[27]	UK	115 (58 in the intervention group and 57 in the control group)	35·0 (11·5)	Four components: free meat substitutes, information leaflets about the health and environmental benefits of eating less meat, recipes, and success stories of people who reduced their intake	No intervention	4 weeks	Primary outcome was change in meat consumption (g); secondary outcomes were psychosocial variables and greenhouse gas emissions from diet	Education, training, modelling, environmental, and restructuring
Carfora et al (2017)[28]	Italy	124 (62 in the intervention group and 62 in the control group)	19·37 (1·55)	Daily SMS focusing on anticipated regret and a reminder to monitor PMC and not exceed the recommended portion per week	No intervention	2 weeks	PMC (portions per week)	Persuasion
Carfora et al (2019)[29]	Italy	244 (three intervention groups: n=56, n=62, n=58; 68 in the control group)	NR*	14 daily messages on health, environment, or health and environment benefits of reduced RPMC	No message	2 weeks	RPMC (portions per week)	Education
Graham-Rowe et al (2019)[2]	UK	283 (two intervention groups: n=84, n=109; 90 in the control group)	43·3 (12·7)	Participants exposed to either standard† or integrated‡ self-affirmation manipulation before reading a message about the negative consequences of food waste and how to reduce fruit and vegetable waste	Participants presented with a list of values and asked to choose the least important; no message about food waste	One-time event	Fruit and vegetable waste (portions per week)	Persuasion
Lacroix and Gifford (2020)[30]	Canada	165 (two intervention groups: n=43, n=44, n=47; 31 in the control group)	32·6 (10·0)	News story with information on health and environmental consequences of RPMC with descriptive social norm and either information on substitution of red meat or information on new healthy recipes with plant-based proteins; participants also wrote out a specific behavioural goal and were guided to an implementation plan and asked to make a behavioural commitment	Unrelated survey	One-time event	Primary outcome was animal product consumption (portions per week); secondary outcome was greenhouse gas-weighted animal product consumption	Training, education, modelling, and enablement
Morren et al (2021)[31]	Netherlands	733 (four intervention groups: n=140, n=145, n=149, n=148; 151 in the control group)	50·0 (17·6)	Online survey of information nudges: declarative environment information, declarative health information, procedural environmental information, and procedural health information	No intervention	One-time event	Meal emissions (kg of CO_2-equivalent)	Education, training, and persuasion
Wolstenholme et al (2020)[32]	UK	251 (three intervention groups: n=58, n=67, n=69; 57 in the control group)	20·00 (1·77)	Participants received SMS messages on the positive effects of eating less red meat on either health, the environment, or a combination	No message on the effects of meat consumption	2 weeks	RPMC (servings per week)	Education

(Table 1 continues on next page)

on a per capita basis. Studies were eligible for inclusion if they used individual-level behaviour change interventions with the aim of promoting healthy and environmentally sustainable dietary behaviour (eg, sustainable dietary habits), defined by the EAT–*Lancet* Commission,[1] or if they promoted sustainable food-waste practices. The study comparison had to be standard care or any intervention to a lesser extent. Studies were eligible if they had a change in diet (defined as either an increase in consumption of plant-based foods and a decrease

	Country	Participants, n	Mean age, SD	Intervention	Control	Duration	Outcomes	Intervention function
(Continued from previous page)								
Quasi-experimental trials								
Hekler et al (2010)[33]	USA	100 (28 in the intervention group and 72 in the control group)	NR*	Experimental course called Food and Society: Exploring Eating Behaviors in a Social, Environmental and Policy Context (Food and Society), for which students read a selection of books, watched documentaries, and discussed major themes in class; assignments included writing an op-ed and creating a YouTube video advocating for behaviour change	Three comparison courses called onHealth Psychology, Community Assessment/Health, and Obesity: Clinical/ Societal Implications	One semester	Changes in diet§ (servings per week)	Education
Jay et al (2019)[34]	USA	163 (90 in the intervention group and 73 in the control group)	NR*	Freshman course series called Food: a Lens for Environment and Sustainability, covering lecture material on general environmental science, an analysis of reading on the environmental footprint of various types of meats, and classroom exercises to calculate the environmental footprint of typical foods	Course series called Evolution of the Cosmos and Life	1 year	Primary outcome was beef servings (per week); secondary outcome was dietary carbon footprint (g of CO_2-equivalent per day)	Education
Lorenz-Walther et al (2019)[34]	Germany	556 (263 in the intervention group and 293 in the control group)	19–23	Two components: reducing portion size of specific target dishes in the canteen¶ and a poster emphasising the issue of food waste, including a request to reduce portions‖	Baseline—no changes	6 weeks	Food left over**	Education, persuasion, environmental, and restructuring or restriction
Malan et al (2020)[35]	USA	176 (89 in the intervention group and 87 in the control group)	NR*	Foodprint seminar: a one-unit academic course on connections between food systems and environmental sustainability, incorporating academic readings, written reading reflections, group discussions, and skills-based active learning exercises	Unrelated one-unit course	One semester	Primary outcome was dietary intake (servings per week); secondary outcome was dietary carbon footprint (g CO_2-equivalent per day)	Education
Prescott et al (2019)[36]	USA	256 (95 in the intervention group and 161 in the control group)	11·32 (0·99)	Healthy Planet Healthy Youth curriculum: five lessons from Farm to Table and Beyond were introduced into sixth graders' science curriculum; students were also asked to calculate their school food waste over the course of a week and create a poster to teach the seventh and eighth grade students in their school; at each school, students also voted for the best poster to hang up in the school cafeteria	No curriculum for seventh and eighth graders	One unit during science class	Plate waste (g) and fruit and vegetable consumption (%)	Education

Where mean age was not reported, the range is reported instead. NR=not reported. PMC=processed meat consumption. RPMC=red and processed meat consumption. *No information was available for age, but the study was completed in university students. †Participants tasked to read a list of values (ie, conscientiousness, spirituality or religiousness, compassion, intelligence, generosity, trustworthiness, creativity, hedonism, friendliness, kindness, and spontaneity) and select their most important value and give three reasons why it was important and an example of something they had done to show the importance of the value to them. ‡Participants were presented with a different list of values (ie, conscientiousness, morality, compassion, commitment, determination, resourcefulness, intelligence, open-mindedness, creativity, enthusiasm, and competence) and asked to select their most important value from the list, then asked why it was important to them and how it had influenced things that they had done. Following this process, these participants were presented with a message that read "The good news is that if any of these values are important to you, you are likely to be successful in reducing your household food waste." §Fruit and vegetables, high-fat dairy, high-fat meat, processed foods, and sweets. ¶Reduction in portion size was defined as serving a small portion of meat (from more than 120 g to 140 g) or using smaller scoops for sauces with meat (from more than 83 g to 100 g). ‖"Reminder to only take so much food that one is able to finish" and "Option to ask for a smaller portion size at the food service counter." **No food left over was the outcome measure.

Table 1: **Study characteristics**

in consumption of meat products or a decrease in meat consumption alone), food waste, or greenhouse gas emissions as a primary or secondary outcome, with the presence of outcomes for change in diet or food waste being the minimum requirement for inclusion. Data for health outcomes (ie, weight and blood lipids) were extracted if available, but did not dictate inclusion. Randomised controlled trials and quasi-experimental trials were eligible for inclusion. Randomised controlled trials are viewed as the gold standard and offer stronger

evidence of causality. Quasi-experimental trials were also included because we expected that few randomised controlled trials would have been completed in this area and quasi-experimental trials can also provide evidence of causality.

Studies were excluded at full-text screening if they met the exclusion criteria (figure 2). Online choice experiments were excluded because they measure hypothetical behaviour change rather than being true interventions, and this systematic review was interested in actual consumer behaviour change measures. Interventions reporting only a change in fruit and vegetable consumption without also reporting a change in foods with a higher environmental impact were excluded because an increase in fruit and vegetables alone is insufficient in changing dietary greenhouse gas emissions.[43,44] Studies not reporting individual-level measures of change were excluded, because we intended to identify the effectiveness of interventions on individual behaviour change.

Search strategies were developed with the assistance of librarians and completed by one reviewer (NMW). Titles and abstracts were screened by three independent reviewers (NMW, KC, YWK) and excluded if they did not meet eligibility criteria. Full-text articles were reviewed to ensure eligibility by three reviewers (NMW, KC, YWK). In the case of uncertainty, an independent reviewer (RG) was consulted. Additional studies were identified through backwards and forwards citation tracking for all included studies.

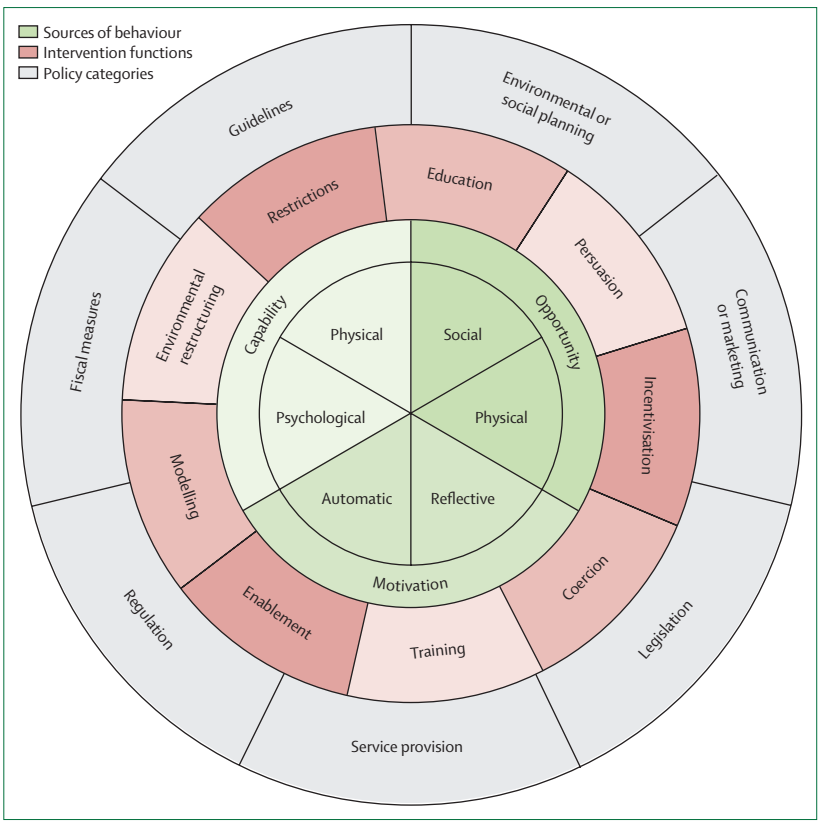

Figure 1: **The behaviour change wheel: COM-B model**
Reproduced from Michie et al,[37] by permission of the authors.

Data analysis

Descriptive data extracted were year of publication, study design, country, number of participants, age, gender, setting of intervention, duration of intervention, follow-up period, and intervention and control characteristics and description. Outcome data extracted were mean reduction in food waste (g, %, etc), mean changes in meat consumption (servings per day or week, g, etc), or mean changes in plant-based consumption (servings per day or week, g, etc). Changes in dietary greenhouse gas emissions were extracted in kg of CO_2-equivalent and health outcomes were extracted as weight (kg) and lipid profiles (mmol/L).

Details of intervention characteristics were classified according to the nine intervention functions of the behaviour change wheel (figure 1): education, restrictions, persuasion, incentivisation, coercion, training, enablement, modelling, and environmental restructuring. Interventions were classified according to examples and definitions given by Michie and colleagues.[37] For example, one study[28] used SMS reminders with a reminder to monitor processed meat consumption and not exceed the recommended portion of processed meat per week. These messages were focused on anticipated regret, and therefore this study was classified as using persuasion. Alternatively, Amiot and colleagues[26] used multicomponent interventions, including a presentation on the health effects of processed meat consumption (education) and on emerging social norms on meat eating in the Canadian population (modelling), a mind attribution task appealing to fear (persuasion), and provision of tips and recipes for meat-free meals (training). Results were quantitatively assessed where applicable using mean changes, and SDs in outcome measures were measured for different intervention functions used alone and those used in combination with multiple intervention functions and presented graphically. In the case that outcome measures were reported differently, outcomes were converted to portions per week for the outcome measure of changes in diet (where one portion was 75 g),[45] grams of food waste for the outcome of food waste, and kilograms of CO_2-equivalent per week for the outcome of dietary greenhouse gas emissions, if applicable. The main outcome measures were changes in diet and food waste.

Risk of bias for randomised controlled trials was assessed using the Cochrane tool for risk of bias in randomised control trials[46] and given a rating of high, low, or some concerns for risk of bias. Risk of bias for quasi-experimental studies was assessed using the ROBINS-I tool by Cochrane.[47] Each study was given a rating of low, moderate, serious, or critical risk of bias. This study is registered with PROSPERO, CRD42022335671.

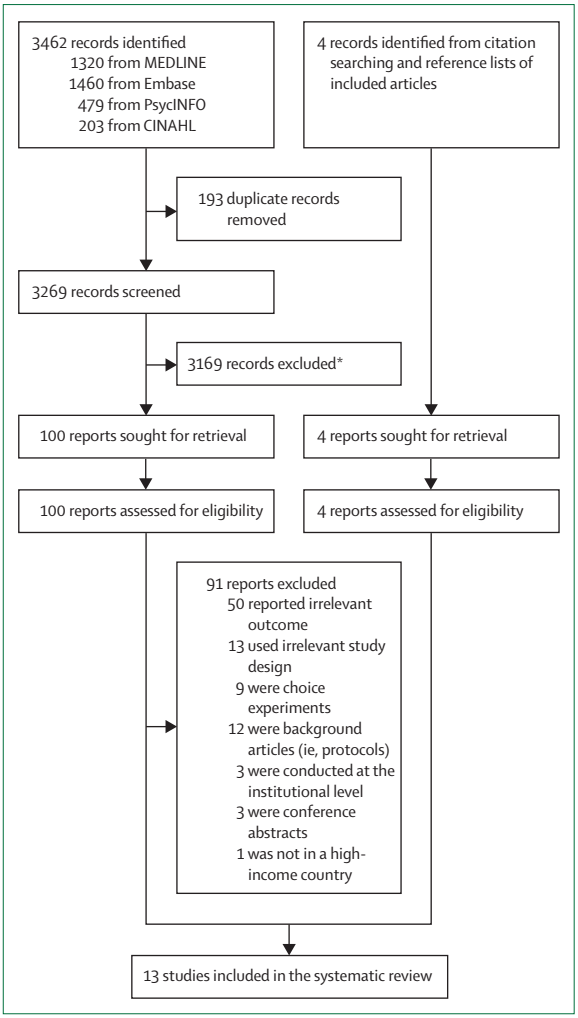

Figure 2: **PRISMA flow diagram**
Template sourced from the PRISMA website.[42] CINAHL=Cumulative Index to Nursing and Allied Health Literature. *Excluded due to being literature reviews, guidelines, position statements, systematic reviews, or not related to dietary behaviour change or environmentally sustainable diets.

Results

Study characteristics

A total of 3466 studies were retrieved from MEDLINE, Embase, PsycINFO, Cumulative Index to Nursing and Allied Health Literature, and citation searching. 3273 were remaining following de-duplication. Following the screening of titles and abstracts, 104 articles were further screened for full-text review. Ultimately, 13 studies were eligible for inclusion in the systematic review (figure 2). Most eligible studies were from nutrition journals and psychology journals.

Eight studies were randomised controlled trials and five were quasi-experimental trials (table 1). Two quasi-experimental studies were pilot studies.[33,35] All studies were published between 2017 and 2021, except for one published in 2010.[33] Studies were conducted across Canada,[26,30] the UK,[2,27,32] Italy,[28,29] the Netherlands,[31] Germany,[34] and the USA, and a total of 3203 participants were included.[14,33,35,36] The mean age of participants was 22·8 years (SD 10·5); one study enrolled only children[36] and one study[26] included only men. Study components were delivered online,[2,30–32] in university classrooms,[14,33,35] in school,[36] via text messages,[28,29] in a laboratory,[26] or to participants at home.[27] Follow-up ranged from 1 week[2,31] to 5 months.[36]

Of the nine intervention functions of the behaviour change wheel, 11 of 13 studies used education,[14,26,27,29,30–36] five used persuasion,[2,26,28,31,34] four used training,[26,27,30,31] three used modelling,[26,27,30] two used environmental restructuring,[27,34] and one used restriction.[34] No studies used enablement, coercion, or incentivisation (figure 3, appendix p 6). Most studies used education alone (n=6),[14,29,32,33,35,36] and others used persuasion alone (n=2)[2,28] or a combination of education and other intervention types (n=5).[26,27,30,31,34]

Changes in diet, food waste, greenhouse gas emissions, and health outcomes

Nine (69%) of 13 studies reported a change in diet measured as a change in meat consumption or whole diets,[33,35] of which six (67%) reported significant reductions.[14,26–29,32] Studies reporting a change in meat consumption reported a mean reduction of 1·47 portions of red or processed meat per week (SD 1·03).

Three (23%) of 13 studies reported primary outcomes of food waste, as grams of food waste,[36] observed plates with no leftovers,[34] and fruit and vegetable servings wasted per week.[2] All studies reported different measures, and therefore an overall mean reduction was unable to be calculated; however, two studies reported significant reductions and one reported non-significant reductions.

Five (38%) of 13 studies reported outcomes on greenhouse gas emissions from diet, reported as kg of CO_2-equivalent per week as a primary outcome[31] or secondary outcome.[14,27,30,35] Three (60%) of five studies reported significant reductions in greenhouse gas emissions from diet[14,27,35] and also reported significant reductions in meat consumption. Three studies used a combination of interventions:[27,30,31] one reported a reduction of 10·5 kg of CO_2-equivalent per week ($p<0·0001$),[27] one reported a reduction of 1·48 kg of CO_2-equivalent per week ($p=0·064$),[31] and one reported no significant changes but did not provide actual values ($p=0·69$).[30]

Only one study reported changes in health outcomes[27] as weight (kg) and by use of blood lipid profiles. Bianchi and colleagues[27] reported a significant reduction in weight of 0·5 kg ($p=0·0037$) that persisted to 8 weeks ($p=0·027$) and no reduction in blood lipid panels at both 4 weeks and 8 weeks.

Intervention functions

11 (85%) of 13 interventions used education alone either on the health or environmental impacts of meat consumption or on food waste (n=6) or in combination with other intervention functions (n=5). Education

included presentations (n=1),[26] posters (n=3),[27,31,34] SMS messages (n=2),[29,32] news stories (n=1),[30] and school (n=1)[36] or university courses (n=3).[14,33,35] Five (83%) of the six studies using education as the sole method of intervention[14,29,32,33,35] reported a mean reduction in red and processed meat consumption of 1·4 portions per week (SD 1·3; figure 4). Two studies[31,32] compared the framing of education around health or environmental benefits and reported that interventions that framed education around environmental issues resulted in greater reductions in servings of meat per week (–3·7 *vs* –2·8, respectively) and in reduction of greenhouse gas emissions (1·2 kg of CO_2-equivalent *vs* –0·1 kg of CO_2-equivalent, respectively). Individually, the studies reported mean reductions in meat consumption of 0·73 portions per week (p<0·01),[28] 1·0 portion per week (p=0·054),[14] and 3·7 portions per week (p=0·00).[32] Hekler and colleagues[33] reported a mean non-significant reduction in meat consumption of 0·9 portions per week, and Malan and colleagues[35] reported a significant within-group mean reduction of 0·7 portions per week (p<0·01). Three studies used a combination of education and other intervention functions,[26,27,30] of which a combination with training, modelling, and environmental restructuring resulted in a mean reduction in meat consumption of 1·1 portions per week (p<0·001);[27] a combination with training, modelling, and persuasion resulted in a mean reduction of 2·24 portions per week (p<0·01);[26] and a combination with training and modelling reported no values and identified no significant changes, but subgroup analysis showed that those assigned to interventions matched to their baseline meat consumption reduced mean red meat consumption by 2·0 portions per week compared with those who were not matched.[30] Similarly, Malan and colleagues[35] reported greater reductions in meat consumption in frequent consumers versus infrequent consumers (–1·5 servings per week *vs* 0·1 servings per week; p<0·001).

Hekler and colleagues[33] and Malan and colleagues[35] both measured changes in vegetable consumption and reported significant improvements in vegetable consumption of 4·2 portions per week (p=0·001) and 4·7 portions per week (p<0·01), respectively, compared with control groups.

Only one study explored food waste as an outcome from an education intervention alone,[36] reporting a 19·2 g reduction in food wasted from an entrée (p=0·876), 2·5 g from salad bar fruit (p=0·04), and 11·5 g from salad bar vegetables (p=0·03).[36] Another study by Lorenz-Walther and colleagues[34] used a combination of education, persuasion, and environmental restructuring or restriction and reported significant improvements in observed leftovers in the intervention group versus the control group (tables 1, 2).

Two studies using education alone reported a mean reduction of 3·1 kg (SD 1·1) of CO_2-equivalent per week

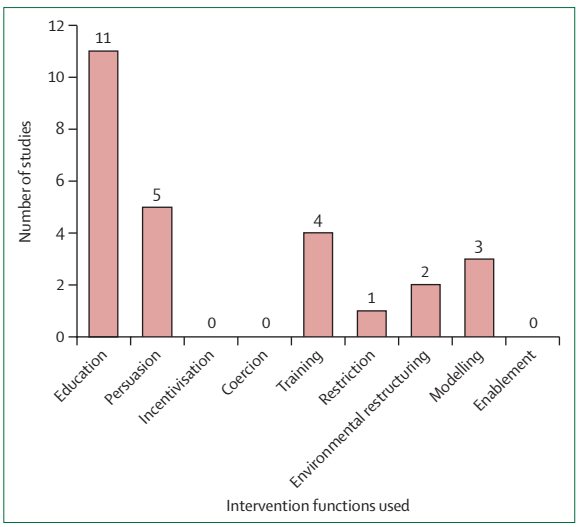

Figure 3: **Intervention functions used in studies**

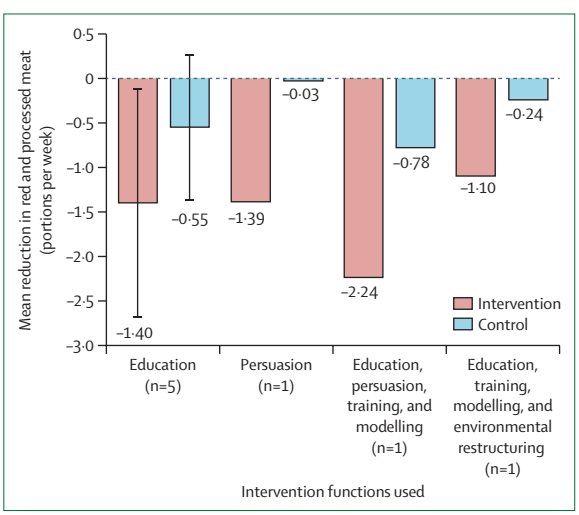

Figure 4: **Effectiveness of interventions on meat consumption**
Mean reduction in portions of red and processed meat per week. SD is represented by bars where more than one study is included in a group.

(figure 5).[14,35] Individually they reported reductions of 3·86 kg of CO_2-equivalent per week (p=0·04)[35] and 2·30 kg of CO_2-equivalent per week (p=0·02).[14]

Four (31%) of 13 studies used training as one part of the intervention[26,27,30,31] through provision of various tips for planning meat-free meals,[26] tips for substituting and choosing meatless options at restaurants,[26] instructions on how to reduce meat consumption,[30,31] and recipes for plant-based meals.[27,30] No studies used training on their own; therefore the effectiveness of their inclusion in multicomponent interventions cannot be quantified accurately.

Five (38%) studies used persuasion alone[2,28] or as a part of the intervention,[26,31,34] and all five studies resulted in significant improvements in meat consumption or food waste. Only one study reported a mean change in

	Food waste in the intervention group	Food waste in the control group	p value for difference between groups
Graham-Rowe et al (2019)[2]	Mean score* of 2·08 in participants exposed to standard self-affirmation manipulation	Mean score* of 3·08	0·034
Graham-Rowe et al (2019)[2]	Mean score* of 2·96 in participants exposed to integrated self-affirmation manipulation	Mean score* of 3·08	0·78
Lorrenz-Walther et al (2019)[34]	210 plates†	214 plates†	<0·05
Prescott et al (2019)[36]	38·8 g‡ at baseline	28·4 g‡ at baseline	0·088
Prescott et al (2019)[36]	19·6 g‡ after intervention	20·6 g‡ after intervention	0·88
Prescott et al (2019)[36]	33·8 g‡ at 5-month follow-up	25·0 g‡ at 5-month follow-up	0·14

*For fruit and vegetable waste per week after intervention. †Plates with observed leftovers after intervention. ‡Plate waste for whole entrée.

Table 2: **Effectiveness of interventions on food waste**

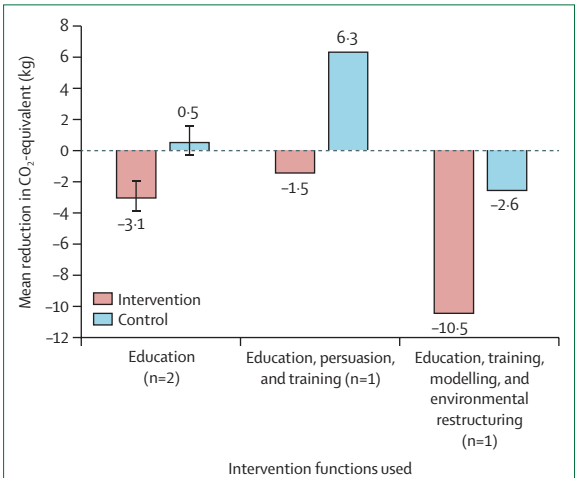

Figure 5: **Effectiveness of interventions on greenhouse gas emissions**
Mean reduction in kg of CO_2-equivalent. SD is represented by bars where more than one study is included in a group.

greenhouse gas emissions of –1·48 kg of CO_2-equivalent per week (p=0·07).[31] Forms of persuasion included mind attribution tasks,[26] anticipated regret and SMS reminders,[28] a request to reduce processed meat consumption[31] or food waste,[34] using self-affirmation to instil value for reducing food waste,[2] or online nudges to reduce meal emissions.[31] Only one study used persuasion alone to influence meat consumption and reported a mean reduction of 1·39 portions per week (figure 4, p<0·05).[28] Two studies incorporated persuasion as a part of a multicomponent intervention and reported reductions of 2·24 portions of red and processed meat per week (p<0·05)[26] and a reduction of 1·48 kg of CO_2-equivalent per week (p=0·07),[31] respectively.

Four (31%) studies reported outcomes on meat consumption and greenhouse gas emissions. Three studies[14,27,35] reported significant reductions in meat servings per week and significant reductions in greenhouse gas emissions measured by CO_2-equivalent per week (–1·1 servings per week [p=0·001], –10·5 kg CO_2-equivalent;[27] –1·0 servings per week [p=0·05], –2·30 kg CO_2-equivalent [p=0·003];[14] –0·7 servings per week [p<0·05, –3·86 kg CO_2-equivalent [p=0·04][35]). One study did not provide actual values but reported no significant changes in either meat consumption or greenhouse gas emissions.[30]

For food waste, Graham-Rowe and colleagues[2] used persuasion alone and reported a lower mean score of food wasted for the standard self-affirmation treatment group and integrated self-affirmation treatment group than for the control group (table 2).

Three (23%) studies used modelling as a part of the intervention, including applying emerging social norms[26,30] or showing stories of people who were successful in reducing their meat consumption.[27] No studies used modelling on their own; therefore the effectiveness of their inclusion in multicomponent interventions cannot be quantified accurately.

Two (15%) studies used environmental restructuring as a part of a multicomponent intervention by providing free meat substitutes to reduce meat consumption[27] and reducing or restricting portion sizes of meat dishes in a canteen to reduce food waste.[34] One of these studies reported reductions of 1·1 portions of red or processed meat per week (p=0·01),[27] and the other study reported a significant difference in the number of plates with no leftovers in the intervention group versus the control group (table 2).[34]

Risk of bias

The risk of bias of the eight randomised controlled trials was assessed using the Cochrane Risk of Bias tool.[46] Three (38%) of eight studies had a high risk of bias, three (38%) had a moderate risk of bias, and two (25%) had a low risk of bias (figure 6). The ROBINS-I tool[47] was used for the remaining five studies to assess risk of bias of non-randomised control trials. Two (40%) of five studies were at serious risk of bias, two (40%) were at moderate risk of bias, and one (20%) had a low risk of bias (figure 7). Most quasi-experimental trials had moderate risk of bias due to bias in confounding, where most studies allowed participants to self-allocate into studies. Some randomised controlled trials did not provide information on their pre-analysis plan, therefore received a moderate risk of bias due to selective reporting.

Discussion

Effectiveness of interventions on environmentally sustainable diets

This systematic review investigated the effectiveness of interventions in promoting environmentally sustainable diets, measured by a change in diet (reduction in meat alone or in combination with increased plant-based foods), food waste, dietary greenhouse gas emissions, and

health outcomes. Overall, we identified that education was the most used intervention function and that studies with interventions that included persuasion reported the largest reductions in meat intake and improvements in food waste, followed by training, modelling, and environmental restructuring. These results were similar to those from a previous systematic review,[25] which identified that improvements in knowledge, linking meat to living animals, increasing visibility of vegetarian dishes, and educational courses on how to shop and cook were effective at reducing meat consumption. The 2022 systematic review[25] focused only on interventions addressing a reduction in meat consumption, whereas this systematic review investigated the change in overall diets, food waste, and greenhouse gas emissions, offering a novel overview of sustainable consumption patterns.

The COM-B model claims that any behaviour change will occur only when the person has the capability and opportunity to engage in the behaviour and is motivated to enact that behaviour. The intervention functions presented within the behaviour change wheel are thought to elicit these three components (appendix p 6). In this systematic review, interventions incorporating persuasion, an intervention function that elicits motivation, resulted in greatest reductions in portions of red or processed meat per week and food waste. For example, in two studies using multicomponent interventions, Amiot and colleagues[26] incorporated persuasion and reported a greater reduction in meat consumption than Bianchi and colleagues.[27] This difference shows that appealing to emotions to elicit the motivation to enact the desired behaviour change might be an important and necessary component in interventions to enable a substantial change in sustainable dietary patterns.[38] The Broaden-and-Build Theory[49] suggests that positive emotions work on motivation through opening our minds, expanding awareness, and facilitating the development of knowledge and skills. By contrast, the elicitation of negative emotion results in the narrowing of options to change behaviour to one that is best suited for survival,[49] ultimately suggesting that, through persuasion (ie, stimulating emotion), people might feel more inclined to enact a change in behaviour. Notably, the few studies using persuasion alone make it difficult to draw conclusions from these results.

In this systematic review, the studies using more than one function reported larger reductions in portions of meat per week (1·1–2·24) and food waste than studies that used education alone, with the exception of one study that reported no significant differences.[30] The use of more than one intervention function might be superior due to their ability to address more than one behavioural component of the COM-B model (ie, capability, opportunity, and motivation; appendix p 6). Notably, the inclusion of behaviour change techniques, such as self-monitoring measures, resulted in greater reductions in portions of meat per week in interventions that used education alone (–3·7 portions, 50% reduction from baseline)[32] than in interventions without self-monitoring (–1·0 portions).[14] These results are likely to be due to self-monitoring acting as a method to reinforce the educational component of the intervention or enabling an individual to observe, measure, and evaluate their own behaviour, prompting or acting as a reminder for them to engage in the desired behaviour change. A previous systematic review corroborated these findings, reporting that interventions were most effective when they combined education and self-regulation strategies.[50]

Amiot and colleagues[26] and Bianchi and colleagues[27] both used multicomponent interventions involving education, training, and modelling. Bianchi and colleagues[27] also incorporated environmental restructuring, which addresses opportunity (appendix p 6), yet did not result

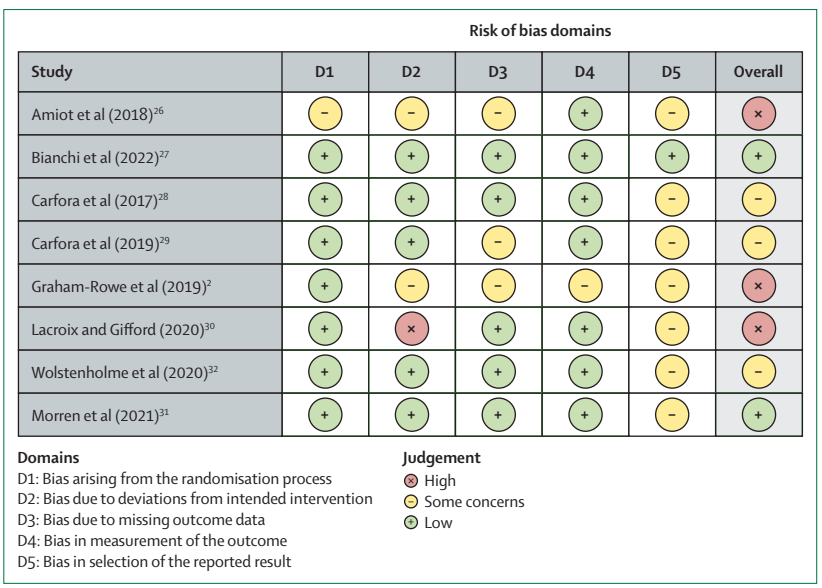

Figure 6: **Risk of bias for randomised controlled trials**
Figure created with robvis.[48]

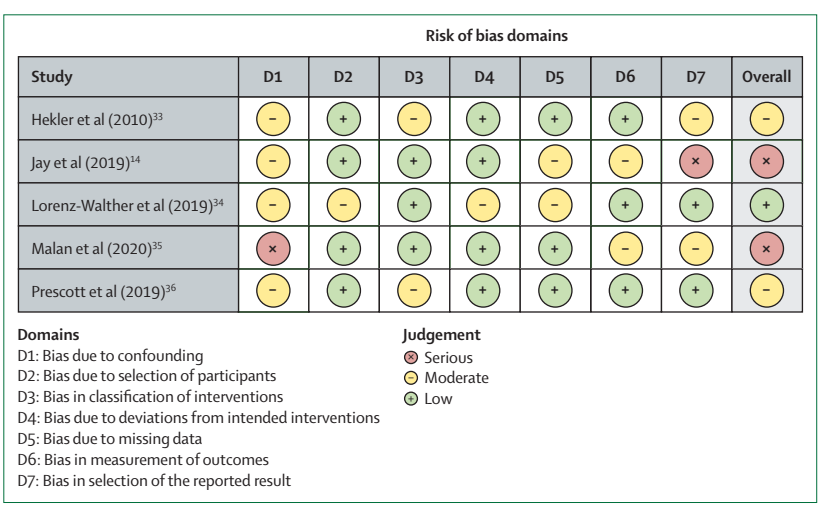

Figure 7: **ROBINS-I tool for quasi-experimental trials**
Figure created with robvis.[48]

in large reductions in meat consumption. This absence of large reduction is despite the increase in availability of plant alternatives in high-income countries, an industry which is now worth US$1·6 billion in the UK,[51] which provides sufficient opportunity for individuals to change dietary meat consumption; however, individuals might not have the motivation and capability to enact the behaviour. The behaviour change wheel suggests that social norm interventions might address deficits in motivation and therefore labelling interventions might address deficits in capability. However, current research is inconsistent on the effectiveness of ecolabels[52] and social norm messaging[53] when used alone. Barriers to uptake, such as the sensory quality of plant-based options, tradition and familiarity, and the perceived health profile of conventional meat,[54] might counteract the motivation or capability to use the plant-based options that are available. The popularity of plant-based meat alternatives has decreased since 2021, indicating that the market might have been overestimated. The success of plant-based dairy alternatives might be more apparent than for meat alternatives due to the difference in taste being less obvious. Food choices are made sub-consciously,[55] and so, presumably the point-of-purchase motivation should emphasise personal preferences, such as taste, freshness, and familiarity, rather than perceived societal benefits (eg, those shown on ecolabels).

Given their low availability, increased interventions addressing opportunities to reduce food waste might be needed. The use of date labels to reduce food waste has been cited in the literature, with a focus on educating individuals on the meaning of the dates.[56] Most reform has focused on changing the phrase (sell by, use by, etc); however, one study[57] reported that consumers are more fixated on the date than on the phrase, suggesting that reform on the actual selection of the date printed on containers needs to be discussed. Another review[58] from 2019 identified that plate size and changing school guidelines also had some effect in reducing food waste in schools.

No studies used training, modelling, restriction, or environmental restructuring alone; therefore the effect of these functions alone on dietary behaviour is not clearly understood. This research does however provide explanation for the role of these interventions to support behaviour change (appendix p 6). For instance, Morren and colleagues[31] included education, training, and persuasion and reported significant reduction in greenhouse gas emissions from meat in the procedural group compared with the declarative group, indicating that, for successful behaviour changes, interventions should provide valid strategies for behavioural modification or training to enhance physical capability in combination with addressing motivation and psychological capability (ie, education). Modelling, targeting automatic motivational processes, was effective in two of the three interventions presented. However, a different quasi-experimental study[53] identified that solely using dynamic social norm messaging was not effective in shifting customers' choice from meat-based to plant-based meals, suggesting that modelling might work best in conjunction with other intervention functions. Ultimately, gaps in the research base are apparent, especially in understanding the distinctive role of interventions in promoting behaviour change. There are usually positive associations between pro-environmental behaviours, meaning that through eliciting a change in one aspect of pro-environmental purchasing, a spillover of effect might occur in other areas of pro-environmental behaviour.[59] Studies have specifically identified positive spillover from green purchase behaviour (ie, consumers purchasing products that cause lower environmental impact) to other pro-environmental behaviour through the use of monetary incentives or verbal praise.[60] These findings suggest that the ability to elicit a change in one aspect of pro-environmental behaviour (eg, diet, purchasing, or food waste) from one intervention type might cause a spillover and cause the individual to also exhibit a change in another pro-environmental behaviour. The study[60] also identified that the spillover occurs only in low-cost behaviours, suggesting the need for opportunity to be addressed.

Furthermore, this systematic review identified alternative considerations to include in interventions attempting to shift dietary habits. Tailoring the intervention to address the individual's current meat intake and knowledge levels might allow for enhanced effectiveness. Three studies[30,33,35] reported no significant reduction in meat consumption; however, subgroup analysis showed that participants who reported frequent meat consumption at baseline had significantly decreased consumption compared with infrequent consumers. This difference might be due to those with the highest consumption having more opportunity to shift diets than those who already consume low levels of meat, emphasising a relevant limitation in behaviour change research; however, considering most of the population consumes large quantities of meat, these interventions should be effective and relevant in many high-income countries. Additionally, studies framing education around environmental issues related to meat consumption resulted in more significant change than those solely focusing on health benefits. This difference might be because information framed around wider environmental benefits promotes the appeal that an individual's actions (ie, dietary choice) are beyond the individual and benefit the population[61] and enable psychological capability and motivation (COM-B) to elicit positive or negative feelings about a behavioural target, ultimately enabling the behaviour change. Research has suggested that individuals with more altruistic and biospheric values were more self-determined to act pro-environmentally compared with individuals without altruistic and biospheric values; thus, providing information on

environmental issues might enhance these values within people to reinforce the change to pro-environmental behaviours.[62]

In this systematic review, results suggested that interventions that significantly reduced meat consumption resulted in significant reductions in greenhouse gas from diet (measured by CO_2-equivalent), with Jay and colleagues[14] reporting that a reduction of as little as one serving per week would also have significant effects on greenhouse gas emissions. However, there was no clear correlation between a reduction in meat consumption and total dietary greenhouse gas emissions, possibly due to the use of different lifecycle assessment values, creating difficulty in the ability to quantify an appropriate reduction in meat to aim for in public health interventions.

Policy recommendations

The diversity of studies and intervention implementations represents challenges for generalisability, and thus direct policy recommendations cannot be made. The results indicate that, according to the policy recommendations in the behaviour change wheel, governments could put forth a multifaceted policy that evokes motivation and capability through the use of mass media campaigns to educate, teach, and persuade individuals; establishes service provision in communities to influence their physical capability and self-efficacy to partake in the behaviour change; and influences the physical opportunity to acquire foods (ie, taxes, rules, or guidelines on red and processed meat consumption or improving access to plant-free meat alternatives). Most studies used a mixed-methods design, tailoring the intervention on the basis of specific population data, suggesting that for appropriate intervention design and implementation, similar pre-implementation tasks should take place to ensure a successful and appropriate policy. Finally, this systematic review might provide insight into future directions of policy and guideline development and stresses the need for more research to support policy development.

Strengths and limitations

This systematic review reported on studies from six different high-income countries. A key limitation in the review was the few randomised controlled trials related to meat reduction and food waste, and only one study directly measured health outcomes. Ten of 13 studies had moderate or high risk of bias, suggesting low quality of most interventions and thus limiting the usefulness of study findings. Additionally, sample sizes were small in most studies, creating difficulties in detecting true change. Heterogeneity between study outcomes and interventions prevented the use of a meta-analysis, therefore limiting the conclusions drawn from the systematic review. A further limitation is the different variations of food diary instruments used, which might reflect differences in the magnitude of effectiveness. Alternatively, a key strength of the systematic review is the use of randomised controlled trials in most studies (ie, eight of 13 studies), allowing for measurements of differences between control and intervention groups, making such differences more likely to be due to the intervention than various confounding factors, provided the intervention was appropriately designed. Most evidence on dietary behaviour change comes from observational studies, which might be subject to a large degree of confounding.

To date, this systematic review is the first to use the behaviour change wheel as a framework classification and for post-hoc analysis, and therefore there are some limitations to address. Although definitions of intervention functions were provided, post-hoc classification of the interventions might be subject to bias of the reviewers. To avoid this bias, two reviewers independently classified interventions. Any discrepancies were discussed with a third reviewer. This systematic review intended to identify, classify, and report the effectiveness of the different intervention functions on promoting environmentally sustainable diets to inform future interventions and policy at the local and national level. We did not report information on the specific behaviour change techniques used, which might limit the association that can be derived from the intervention and the outcome. To effectively investigate the association between the intervention content and outcome, a taxonomy of behaviour change techniques for each intervention function should be developed but is beyond the scope of this systematic review. Intervention functions will comprise many different behaviour change techniques, and any one behaviour change technique might serve more than one intervention function; therefore, on identifying effective intervention functions, it is possible to select more precise behaviour change techniques on the basis of existing literature.[63,64]

Conclusion

This Review is the first to systematically investigate interventions promoting environmentally sustainable diets, addressing four distinct components (ie, diet, food waste, greenhouse gas, and health outcomes) to influence planetary health. The behaviour change wheel was used as a framework to classify components of the interventions according to the nine intervention functions and to provide insight into the determinants of behaviour change and how various interventions might facilitate behaviour change. Overall, interventions using persuasion were the most successful intervention tactic; however, further research is needed for the effectiveness of its use alone to initiate change. Educational interventions were the most used but were most successful when combined with other components addressing motivation and capability, such as persuasion, training, or modelling, and to a lesser extent, environmental restructuring or restriction. Therefore, on the basis of the findings from this systematic review, multicomponent interventions are more effective at

shifting dietary behaviour than single component interventions. This conclusion showcases the need to move away from interventions placing sole responsibility of behaviour change on the individual, and instead fostering an environment where individuals are capable, motivated, and have substantial opportunity for change.

Contributors

NMW designed the study and completed the search strategy with the assistance of a librarian. NMW, KC, and YWK did the screening and full-text review, with uncertainty addressed by RG. NMW and KC completed the data extraction. NMW completed data analysis and wrote the research. RG assisted in screening, data extraction, and editing of the research drafts.

Declaration of interests

We declare no competing interests.

Data sharing

Data collected for the analysis included baseline and postintervention values of greenhouse gas emissions, meat and vegetable consumption, and health outcomes. These data will be made available on request to noormajdiwadi@gmail.com or n.wadi@nhs.net.

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