Meta-Analysis

Reducing meat and/or dairy consumption in adults: a systematic review and meta-analysis of effects on protein intake, anthropometric values, and body composition

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Context: *Consumers are increasingly encouraged to reduce meat and dairy consumption. However, few meta-analyses of randomized controlled trials (RCTs) on the effect of reducing meat and/or dairy on (absolute) protein intake, anthropometric values, and body composition are available.* ***Objective:*** *The aim of this systematic review and meta-analysis was to evaluate the effect of reducing meat and/or dairy consumption on (absolute) protein intake, anthropometric values, and body composition in adults aged* $\geq$ *45 years.* ***Data Sources:*** *The MEDLINE, Cochrane CENTRAL, Embase, ClinicalTrials.gov, and International Clinical Trials Registry Platform databases were searched up to November 24, 2021.* ***Data Extraction:*** *Randomized controlled trials reporting protein intake, anthropometric values, and body composition were included.* ***Data Analysis:*** *Data were pooled using random-effects models and expressed as the mean difference (MD) with 95%CI. Heterogeneity was assessed and quantified using Cochran's Q and* I^2 *statistics. In total, 19 RCTs with a median duration of 12 weeks (range, 4–24 weeks) and a total enrollment of 1475 participants were included. Participants who consumed meat- and/or dairy-reduced diets had a significantly lower protein intake than those who consumed control diets (9 RCTs; MD,* -14 *g/d; 95%CI,* -20 *to* -8*;* $I^2 = 81\%$*). Reducing meat and/or dairy consumption had no significant effect on body weight (14 RCTs; MD,* -1.2 *kg; 95%CI,* -3 *to 0.7;* $I^2 = 12\%$*), body mass index (13 RCTs; MD,* -0.3 *kg/m*^{2}*; 95%CI,* -1 *to 0.4;* $I^2 = 34\%$*), waist circumference (9 RCTs; MD,* -0.5 *cm; 95%CI,* -2.1 *to 1.1;* $I^2 = 26\%$*), amount of body fat (8 RCTs; MD,* -1.0 *kg; 95%CI,* -3.0 *to 1.0;* $I^2 = 48\%$*), or lean body mass (9 RCTs; MD,* -0.4 *kg; 95%CI,* -1.5 *to 0.7;* $I^2 = 0\%$*).* ***Conclusion:*** *Reduction of meat and/or dairy appears to reduce protein intake. There is no evidence of a significant impact on anthropometric values or body composition. More long-term intervention studies with defined amounts of meat and dairy are needed to investigate the long-term effects on nutrient intakes and health outcomes.*

Systematic Review Registration: *PROSPERO registration no. CRD42020207325.*

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Key words: aging, meat and dairy-reduced diet, meat-free diets, nutrients, protein, sustainability.

INTRODUCTION

Consumers are increasingly encouraged to reduce meat and dairy consumption for both health and environmental reasons.[1,2] Production of meat and dairy products requires substantial resources and contributes to a large share of anthropogenic greenhouse gas emissions,[3] accounting for two-thirds of the greenhouse gas emissions from the livestock sector.[4] While the environmental burden is much higher for meat production than for dairy production,[5,6] overconsumption of dairy is estimated to be similarly environmentally harmful as a habitual diet rich in meat products.[7] On the other hand, meat and dairy are inseparable, as their production is closely interlinked.[8,9] Nutritionally, these products are also linked by their contribution to a large share of proteins in human diets.[7,10]

Despite growing interest in meat- and dairy-reduced diets, reducing the consumption of these food products remains debatable because of health and nutritional concerns.[11–13] The debate on reducing meat and dairy consumption is centered on the important role of these foods as a source of high-quality nutrients such as protein, iron, zinc, and vitamin B_{12}.[10,14] While protein may be replaced by other plant-based sources in well-planned diets, diets devoid of meat and dairy are usually low in iron, zinc, and vitamin B_{12}.[15,16] Indeed, mounting evidence warns about the re-emergence of nutritional deficiencies if meat- and dairy-reduced diets are adopted globally,[17–19] with negative health effects expected in vulnerable groups, including children, women of reproductive age, and the elderly.[14,20] Further, studies have suggested that substituting meat and dairy negatively impacts protein intake.[21–23] The negative effect on protein intake appears to be worse in older adults and the elderly than in the general population.[24] Another worrying change is the increase in the consumption of carbohydrates and sugars when meat and dairy are reduced or eliminated from the diet.[23,25]

High-quality animal proteins are required to synthesize muscle protein.[26] The capacity of the muscle to synthesize protein declines with aging.[27,28] Likewise, aging is also associated with a progressive loss of muscle mass and function,[29] a bodily change that begins in the early 40s or 50s.[30,31] Dietary interventions entailing adequate protein intake and a physically active lifestyle may attenuate the decline of muscle mass induced by aging.[32] In fact, a recent meta-analysis has shown that a protein intake of 1.2 to 1.59 g/kg/d increases muscle mass in older adults.[33] On the other hand, aging is also accompanied by fat accumulation as lean tissue declines.[34,35] Consequently, with an increasingly aging global population,[36] this raises concerns that shifting to meat- and dairy-reduced diets could also increase the risk of poor health in this population.[37–40]

Overconsumption of meat and dairy has both individual and global effects, as high meat consumption is associated with obesity[41] and with increased greenhouse gas emissions.[42,43] However, the recommendation of reduced meat and dairy consumption is aimed at affluent societies,[44] in which consumption of these food groups and, therefore, protein intake, is generally high.[45,46] In this context, it is usually assumed that meat and dairy foods are replaced with (healthy) plant-based whole foods, such as legumes, vegetables, and fruits.[45,47,48] On the contrary, however, consumers are also increasingly consuming other processed plant- and non-plant-based food substitutes, which impacts nutrient intake and overall health.[25,49] Additionally, the *food substitution effect* is another factor that is also overlooked in the discourse on reducing meat and dairy intake. Altering the consumption of one food or food group(s) is inevitably followed by changes in the intake of other foods,[21,50,51] and reducing the intake of one macronutrient affects either energy intake or the intake of other macronutrients.

Moreover, mounting evidence shows that reducing meat and dairy consumption can also benefit health.[52,53] Most of the evidence comes from reviews that compared populations who habitually consume meat and dairy (omnivores) with those who do not, such as vegans.[54–59] Additionally, most reviews of the effect on (absolute) protein intake provide only a narrative synthesis,[20,56,60,61] and meta-analyses of the effect of reducing meat and dairy on (absolute) protein intake are still lacking. Therefore, this review evaluated the effect of reducing meat and/or dairy consumption on protein intake, anthropometric measurements, and body composition in adults aged 45 years and older. In addition to examining the effect of reducing meat and dairy consumption, this review also explored whether the effect differed for different degrees of reduction, types of interventions, and types of food substitutes.

METHODS

A systematic review and meta-analysis of randomized controlled trials (RCTs) was conducted to evaluate the effect of reducing the consumption of meat and/or dairy on protein intake, anthropometric measurements, and body composition. This review was designed and is reported following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[62] The PRISMA table is provided as Appendix S1 in the Supporting Information online. The review protocol is registered in PROSPERO under the identification number CRD42020207325.

Eligibility criteria

The PICOS (Population, Intervention, Comparison, Outcomes, Study design) strategy was used to define search strategies and establish eligibility criteria (Table 1). Briefly, studies were selected for this review if they met the following 5 criteria: (1) randomized trials with parallel design, (2) recruitment of participants habitually consuming meat and dairy, (3) participants assigned to either sustain their diet or reduce meat and/or dairy, (4) inclusion of participants with the average age of 45 years or older, and (5) follow-up duration of at least 4 weeks. The age criterion was based on evidence that middle adulthood marks the beginning of adverse body composition changes after the peak of growth and development is attained.[29,30] Studies investigating the postprandial effect of meat-reduced diets were excluded. No restriction was placed on caloric differences between experimental diets within and across trials. There was also no restriction on the year or language of publication.

Search strategy and study selection

A systematic search was conducted using a predesigned search strategy (see Table S1 in the Supporting Information online). The following databases were searched: MEDLINE, Cochrane Central Register of Controlled Trials (CENTRAL), Embase, International Clinical Trials Registry Platform (ICTRP), and ClinicalTrials.gov. A free-text search in Google Scholar was also conducted. The literature search was performed on November 24, 2021.

Two reviewers (T.H. and E.E.) independently screened the identified titles and abstracts, using the Rayyan screening tool in blind mode.[63] The full texts of identified articles were also independently screened in duplicate. Discrepancies were discussed between the two reviewers, and other members were involved when consensus could not be reached.

Data extraction

The lead author (T.H.) extracted the data using a predesigned form (Excel spreadsheet), and two other authors (J.D. and I.M.S.E.) independently checked the data. The following data were retrieved: author(s) and year of publication; country; study design; study duration; funding sources; number of participants included in the analyses; sex; mean age or age range; characteristics of participants (healthy or with chronic disease conditions); description of interventional diets; type of intervention (behavioral or dietary); form of dietary reduction (meat only, dairy only, or both meat and dairy); types of food substitutes used (whole foods or processed meat and dairy substitutes); degree of dietary reduction (partial or total); cointerventions (reduction of other animal-derived foods, including fish and/or eggs); protein sources used to replace meat and dairy (legumes only, legumes mixed with animal foods, and nonlegumes); description of control diets; data on outcomes (protein intake, body weight, body mass index (BMI), waist circumference, body fat, and lean body mass); and ad hoc dietary restrictions (energy restriction vs ad libitum consumption, and isocaloric vs non-isocaloric diets). Study authors were contacted for missing data, and data were acquired from two authors.

The mean and standard deviation (SD) were retrieved from each study arm at the endpoint. If data were reported as confidence intervals and/or the standard error of the mean, the SD was computed on the basis of the mean and the number of participants in the study arms. Where studies reported data in different units, the data were converted using the International System of Units.[64]

Statistical analyses

Statistical analyses were performed using Stata software (version 17) and Cochrane's Review Manager (RevMan) software, version 5.4.1.[65] Data were pooled using random-effects models for all outcomes and were presented as mean differences (MDs) with 95%CIs, with significance considered at $P < 0.05$. Multiple intervention and control arms from the same study were combined using a weighted average to allow single comparisons. For subgroup analysis, studies were split on the basis of the following variables: (1) type of intervention, (2) degree of dietary substitution/reduction, (3) type of food substitutes used, (4) form of dietary reduction, (5) sources of protein substitution, (6) cointerventions, (7) energy/calorie restrictions, (8) weight loss intentions, (9) study duration, (10) isocaloric comparison, (11) health status of participants at baseline, and (12) age category.

Table 1 **PICOS criteria for inclusion and exclusion of studies**

Parameter	Criteria
Population	Adults (human) aged ≥ 45 years. No restriction on sex, race, or ethnicity
Intervention	Meat- and/or dairy-reduced diet
Control/comparator	Habitual (standard) diet rich in meat and/or dairy
Outcomes	Protein intake, body weight, body mass index, waist circumference, body fat (fat mass), lean body mass (fat-free mass)
Study design	Randomized controlled trial

Heterogeneity was quantified and tested using Cochran's Q statistic and I^2, with significance set at $P < 0.10$.[66] Heterogeneity was considered as low, moderate, substantial, and considerable for I^2 of $\leq 30\%$, between 30% and 50%, $>50\%$ to 75%, and $\geq 75\%$, respectively.[66] Meta-regression analyses were conducted to investigate the influence of different variables on the effect size.[67,68] In meta-regression, categorical variables were coded using 0 and 1. The effect of large studies was assessed using a leave-one-out meta-analysis.[69] Further sensitivity analyses were performed to investigate the impact of removing studies evaluated as having high risk of bias.

Publication bias was investigated through visual inspection of funnel plots and formally tested using the Egger and Begg tests.[70] Where publication bias was suspected, the trim-and-fill method was performed to impute missing studies.[71]

Exploratory meta-analysis

Reduction or substitution of meat or dairy from the diet inevitably results in the incorporation of other foods, with diverse impacts on nutrients and total energy intake.[50] Therefore, an exploratory meta-analysis was performed to determine whether meat and/or dairy reduction impacted fat, carbohydrate, and total energy intake.

Assessment of risk of bias and quality of evidence

The Cochrane risk-of-bias tool (RoB 2, beta version 7) was used to assess the risk of bias within individual studies.[72] Studies were assigned a low, high, or unclear risk of bias on the basis of the randomization process, allocation concealment, blinding of the participants and/or outcomes assessors, selective reporting, and completeness of the outcomes data. The NutriGrade scoring system for meta-analyses of RCTs was used to evaluate the quality of evidence.[73] Evidence grading was based on 7 items of the NutriGrade's checklist: (1) risk of bias, study quality, and study limitations, (2) precision, (3) heterogeneity, (4) directness, (5) publication bias, (6) funding bias, and (7) study design. Quality of evidence was graded as very low, low, moderate, or high for scores of 0 to 3.99, 4 to 5.99, 6 to 7.99, and 8 to 10, respectively.

RESULTS

Study selection

The literature search generated 4465 records (Figure 1). Removal of duplicates resulted in 3160 records. After titles and abstracts were screened, 150 records were retained for full-text evaluation, 19 of which met the inclusion criteria.

Characteristics and quality of included studies

The 19 included parallel-design RCTs were published between 1986 and 2020 and enrolled a total of 1475 participants (Table 2[74–92]). Of these, 10 enrolled healthy volunteers and 9 enrolled patients in whom chronic disease conditions were diagnosed: type 2 diabetes (6 RCTs),[82,85–89] metabolic syndrome (2 RCTs),[79,83] and insulin resistance (1 RCT)[90]. All but 3 RCTs[74,81,86] enrolled participants with BMIs > 24.9 kg/m^2. One study each was from South Korea[86] and Iran[89]; all others were from Europe, the United States, Canada, Australia, and New Zealand.

Meat and/or dairy was replaced with traditional plant-based whole foods in 15 RCTs (79%)[74,75,77–80,82–85] and with novel plant-based meat or dairy substitutes in 4 RCTs (21%).[76,81,87,92] In 7 RCTs, participants were instructed to eliminate meat and/or dairy products from the diet.[74,78,80,82,86,88,91] Only 3 RCTs specified the amount of meat and/or dairy that was allowed for consumption: 500 g of red meat per week,[92] 12 g of lean beef per day,[83] and 80 g of meat per day.[77] In more than half of the studies (n = 11), fish and/or eggs were excluded in addition to the reduction of meat and dairy.[75,76,78,82–84,86–88,90,91] Meat and/or dairy was replaced with legumes only in 7 RCTs,[78,82,86–88,91] with legumes mixed with animal foods in 6 RCTs,[76,81,83,84,89,90,92], and with other nonlegume foods (such as mushroom, grain, and cereals) in 6 RCTs.[74,75,77,79,80,85] Only one RCT considered the health and sustainability aspects of the interventional diet.[92] In 7 studies, the participants were instructed to

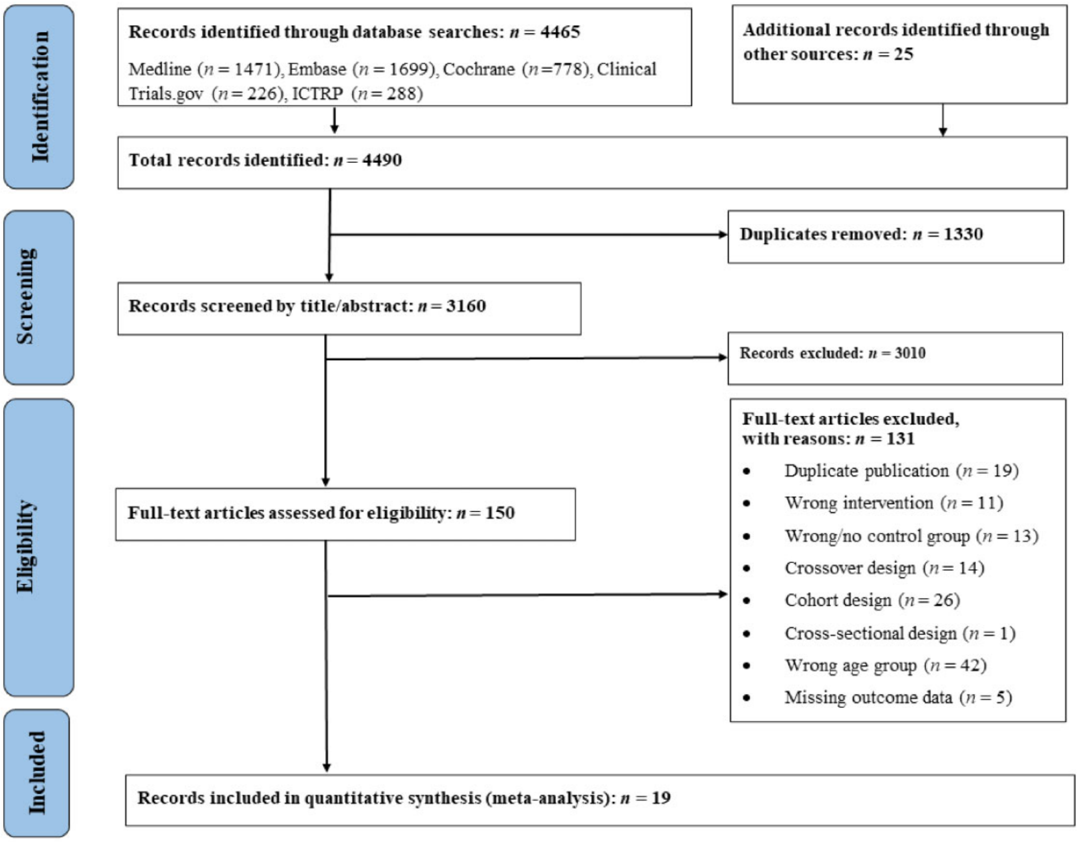

Figure 1 **Flow diagram of the literature search process.** *Abbreviation*: ICTRP, International Clinical Trials Registry Platform.

consume energy-restricted diets,[77,79,80,83,85,88,90] and the energy deficit varied from 500 to 780 kcal/d. Only 4 studies specified the comparison of isocaloric diets.[77,87,89,90] The median duration of the included studies was 12 weeks (range, 4–24 weeks).

Table S2 and Figure S1 in the Supporting Information online summarize the quality assessment of the included studies. As expected in dietary intervention studies, allocation concealment and masking of the participants were uncommon, but masking of trial staff and outcomes assessors was common.[78,80,82,88,91] More than half of the studies (n = 11) also encouraged adherence to interventional diets.[76–83,86,87,90] Compliance with the interventional diets was better in short-term studies (≤ 12 weeks)[86,87,90] than in long-term studies (> 12 weeks)[80,82,83]: 80% to 97% vs 55% to 76%. Most of the trials (n = 13) were assessed as having unclear risk of bias, whereas 4 trials were assessed as having high risk of bias[75,85,87,89] and 2 trials as having low risk of bias.[79,91]

Publication bias and quality of evidence

Funnel plots used to assess the risk of publication bias are presented in Figure S2 in the Supporting Information online. Visual inspection suggests moderate asymmetry for protein intake and body fat. However, the Egger test formal assessment indicates no publication bias for either protein intake ($P = 0.94$) or body fat ($P = 0.57$). Evaluation of the quality of evidence is presented in Table S3 in the Supporting Information online. The quality of evidence was graded as low for body weight (score: 4.8) and body fat (score: 5.75) and as moderate for protein intake (score: 7), BMI (score: 6.0), waist circumference (score: 6), and lean body mass (score: 6.25).

Effect of reducing meat and/or dairy on protein intake

A total of 707 participants from 9 RCTs contributed data to the meta-analysis of protein intake (Figure 2[75,76,78,84,86,88,89,91,92]). The included RCTs had a median duration of 12 weeks (range, 8–24 weeks). On average, participants who consumed the meat- and/or dairy-reduced diets had a significantly lower protein intake (9 RCTs; MD, −14 g/d; 95%CI, −20.4 to −8.3) than the participants who consumed control diets. There was considerable evidence of heterogeneity ($I^2 = 81.6\%$, $P = 0.00001$). Exclusion of the 2 studies at high risk of bias[75,89] did not alter the results (7 RCTs; MD, −16 g/d; 95%CI, −22 to −9; $I^2 = 76\%$). Likewise, iterative removal of individual studies did not alter the

Table 2 **Characteristics of the 19 included randomized controlled trials on reduction of meat and/or dairy consumption**

Reference	Country	Characteristics of participants		Sample size (M/F)	Study duration	Intervention diet	Control diet	Specific aspects of the intervention				Ad hoc dietary instruction or recommendations	
		Health status and BMI	Age					Type of intervention	Form of substitution	Type of substitute	Level of substitution	Energy restriction	Physical activity
Ghadirian et al (1995)[74]	Canada	Healthy post-menopausal women	50–90 y	158 (F)	4 wk	Dairy-free diet	Dairy-containing diet	Dietary	Dairy	Traditional PBWFs Nonlegume protein sources	Total	No energy restriction Non-isocaloric diets	No
Campbell et al (1999)[75]	USA	Healthy men BMI: 27–33 kg/m^2	51–69 y	19 (M)	12 wk	LOV (meat-free) diet	Mixed diet/habitual omnivore diet	Behavioral	Meat Reduction of fish	Traditional PBWFs Nonlegume protein sources	Partial	No energy restriction Non-isocaloric diets	Resistance training
Haub et al (2002)[76]	USA	Healthy men BMI: 28 kg/m^2	65 y	21 (M)	12 wk	LOV diet, including textured vegetable (soy) protein products	Beef-containing diet (LOV diet supplemented with beef)	Dietary	Meat Reduction of fish	Novel PBMDS Legume proteins (soy) + other animal foods	Partial	No energy restriction Non-isocaloric diets	Resistance training
Noakes et al (2005)[77]	Australia	Healthy women BMI: 27–40 kg/m^2	49 y	100 (F)	12 wk	High-carbohydrate dietary pattern (80-g packs of chicken and pork + pasta, rice, biscuits, and whole bread)	High-protein diet (200-g portions of red meat + 100-g lunch portions of meat, chicken, or fish for 6 meals/wk	Dietary	Meat	Traditional PBWFs Nonlegume protein sources	Partial	Energy intake limited to 5600 kJ/d Isocaloric diets	≥ 30 min 3 times/wk
Barnard et al (2005)[78]	USA	Healthy post-menopausal women BMI: 26–44 kg/m^2	44–73 y	59 (F)	14 wk	Low-fat, vegan diet	Mixed diet, complying with NCEP or TLC diet	Behavioral intervention	Meat + dairy Reduction of fish and eggs	Traditional PBWFs Only legume protein sources	Total	No energy restriction Non-isocaloric diets	No
Jones et al (2013)[79]	Canada	Men and women with MetS BMI: 27–37 kg/m^2	20–60 y	38 (M, 14; F, 24)	12 wk	Low dairy or dairy-reduced diet	High-dairy diet	Behavioral	Dairy	Traditional PBWFS Nonlegume protein sources	Partial	500 kcal/d deficit Non-isocaloric diets	No
Poddar et al (2013)[80]	USA	Healthy men and women BMI: 25–40 kg/m^2	48 y	73 (M, 9; F, 64)	24 wk	Mushroom-based diet: replacement of meat with 8 oz of mushrooms for 3 meals per week	Standard diet (meat-based diet)	Dietary	Meat	Traditional PBWFS Nonlegume protein sources	Total	500 kcal/d energy deficit diet Non-isocaloric diets	No

(continued)

Table 2 **Continued**

Reference	Country	Characteristics of participants: Health status and BMI	Characteristics of participants: Age	Sample size (M/F)	Study duration	Intervention diet	Control diet	Specific aspects of the intervention: Type of intervention	Form of substitution	Type of substitute	Level of substitution	Ad hoc dietary instruction or recommendations: Energy restriction	Physical activity
Benatar et al (2014)[81]	New Zealand	Healthy men and women BMI: 24 kg/m^2	47 y	176	4 wk	Dairy reduction or elimination. Advised to consume dairy substitutes (rice- or soy-based products)	Same or usual dairy intake Increased or high dairy intake	Behavioral	Dairy	Novel PBMDS Legume protein sources (soy milk, rice milk) + animal foods	Partial	No energy restriction Non-isocaloric diets	No
Bunner et al (2015)[82]	USA	Patients with T2DM or diabetic neuropathy BMI: 36 kg/m^2	57 y	33	20 wk	Low-fat, plant-based diet: omission of animal-based products; limited intake of fat (20–30 g/d); preference for low-glycemic-index foods	Usual diet or no change in habitual diet	Behavioral	Meat + dairy Reduction of fish and eggs	Traditional PBWFs Only legume protein sources (lentils)	Total	No energy restriction Non-isocaloric diets	No
Hill et al (2015)[83]	USA	Men and women with MetS BMI: 25–40 kg/m^2	30–60 y	34 (M, 15; F, 19)	24 wk	Modified DASH diet: 2/3 of total protein derived from plant sources (pulses, grains, soy, nuts, and seeds). Modified DASH diet contained 12 g of lean beef/d. Modified DASH diet also contained 3 chicken-based meals/wk and 1 fish-based meal/wk	BOLD and BOLD+ diet: 2/3 protein derived from animal foods (lean beef, chicken, tuna, eggs, and dairy). BOLD and BOLD+ diets contained lean beef, 139 g/d and 196 g/d, respectively	Dietary	Meat + dairy Reduction of fish and eggs	Traditional PBWFS Legumes (soy, beans, peas) + other animal foods	Partial	500 kcal/d energy deficit Non-isocaloric diets	Walking

(continued)

Table 2 **Continued**

Reference	Country	Characteristics of participants		Sample size (M/F)	Study duration	Intervention diet	Control diet	Specific aspects of the intervention				Ad hoc dietary instruction or recommendations	
		Health status and BMI	Age					Type of intervention	Form of substitution	Type of substitute	Level of substitution	Energy restriction	Physical activity
Turner-McGrievy et al (2015)[84]	USA	Healthy men and women BMI: 25–49 kg/m^2	18–65 y	68	24 wk	Vegetarian, pescatarian, and semi-vegetarian diets	Usual omnivorous diet	Behavioral	Meat + dairy Reduction of fish and eggs	Traditional PBWFs Legumes + animal foods	Partial	No energy restriction Non-isocaloric diets	No
Ziegler et al (2015)[85]	Germany	Patients with T2DM BMI: 33 kg/m^2	53 y	26	8 wk	Diet free of red meat, high in coffee, and high in cereal fiber (30–50 g/d) from wheat and rye bread	Diet high in red meat ($\geq$ 150 g of beef per day), low in fiber, and free of coffee	Behavioral	Meat	Traditional PBWFs Nonlegume protein sources	Partial	1198 kJ/d energy deficit Non-isocaloric diets	No
Lee et al (2016)[86]	South Korea	Patients with T2DM BMI: 23 kg/m^2	57 y	93 (M, 18; F, 75)	12 wk	Brown rice–based vegan diet	Conventional diet, based on Korean Diabetes Association guidelines	Behavioral	Meat + dairy Reduction of fish and eggs	Traditional PBWFs Only legume protein sources	Total	No energy restriction Non-isocaloric diets	No
Markova et al (2017)[87]	Germany	Patients with T2DM BMI: 28 kg/m^2	49–78 y	37 (M, 24; F, 13)	6 wk	Plant protein–rich diet: protein mainly from legumes (pea protein drinks, pea protein bread), mashed potatoes, noodles, and cookies)	Animal protein–rich diet, mainly meat, fish, and dairy food products	Dietary	Meat + dairy Reduction of fish and eggs	Novel PBMDS Only legume protein sources	Partial	No energy restriction Isocaloric diets	No
Barnard et al (2018)[88]	USA	Patients with T2DM BMI: 33 kg/m^2	61 y	40	20 wk	Vegan diet: vegan meal plan based on low-fat, low-glycemic-index foods, with omission of animal products and added oils. No energy restriction	Usual omnivorous diet, with reduced portion size (equal to deficit of 500 kcal/d)	Behavioral	Meat + dairy Reduction of fish	Traditional PBWFs Only legume protein sources	Total	500 kcal/d energy deficit Non-isocaloric diets	No

(continued)

Table 2 **Continued**

Reference	Country	Characteristics of participants		Sample size (M/F)	Study duration	Intervention diet	Control diet	Specific aspects of the intervention				Ad hoc dietary instruction or recommendations	
		Health status and BMI	Age					Type of intervention	Form of substitution	Type of substitute	Level of substitution	Energy restriction	Physical activity
Hematdar et al (2018)[89]	Iran	Patients with T2DM BMI: 25 kg/m^2	40–65 y	64	8 wk	Cooked soybeans or non-soy-based dietary regimen for 3 d/wk + avoidance of red meat	Red meat–containing dietary regimen (3 d/wk), omitting soy and non-soy legumes	Behavioral	Meat	Traditional PBWFs Legume and soybeans + other animal foods	Partial	No energy restriction Isocaloric diets	No
Basciani et al (2020) [90]	Italy	Patients with drug-naive insulin resistance BMI: 30–40 kg/m^2	50–70 y	48	45 d (6 wk)	Vegetable-protein-based diet (very low-calorie ketogenic diet). Vegetable protein diet, derived from soya, green peas, or cereals and 1 serving of low-glycemic-index vegetables	Two animal protein–based diets: 1. Whey protein–based diet 2. Animal protein–based diet, derived from meat, fish, and eggs	Dietary	Meat + dairy Reduction of fish and eggs	Traditional PBWFs Only legumes and soybeans protein sources	Partial	Energy limited to 780 kcal/d Isocaloric diets	No
Kahleova et al (2020)[91]	USA	Healthy men and women BMI: 28–40 kg/m^2	53 y	223	16 wk	Low-fat, vegan diet based on vegetables, grains, legumes, and fruits, with omission of animal products and added oils	Usual mixed diet containing animal products	Behavioral	Meat + dairy Reduction of fish and eggs	Traditional PBWFs Only legume protein sources	Total	No energy restriction Non-isocaloric diets	No

(continued)

Table 2 **Continued**

Reference	Country	Characteristics of participants		Sample size (M/F)	Study duration	Intervention diet	Control diet	Specific aspects of the intervention				Ad hoc dietary instruction or recommendations	
		Health status and BMI	Age					Type of intervention	Form of substitution	Type of substitute	Level of substitution	Energy restriction	Physical activity
Päivärinta et al (2020)[92]	Finland	Healthy omnivorous men and women BMI: 18–35 kg/m^2	48 y	136 (M, 29; F, 107)	12 wk	Plant-based diet with 70% and 30% of protein derived from plant and animal sources, respectively. Partial replacement of animal-source foods, except fish and eggs. Plant proteins were derived from plant-based products: tofu, nuts, seeds, bread, pulse, and cereals.	Two diets: 1. Animal protein–based diet or average Finnish diet, with 70% and 30% of protein from animal and plant sources (red meat, dairy, and fish), respectively 2. 50/50 animal/plant protein-based diet, with no more than 500 g of red and processed meat per week	Dietary	Meat + dairy	Traditional PBWFs + novel PBMDS Legumes + animal foods	Partial	No energy restriction Non-isocaloric diets	No

Abbreviations: BMI, body mass index; BOLD, beef in an optimal lean diet; BOLD+, beef in an optimal lean diet plus protein; DASH, Dietary Approaches to Stop Hypertension; LOV, lacto-ovo-vegetarian; M-DASH, modified DASH; MetS, metabolic syndrome; NCEP, National Cholesterol Education Program; PBMDS, plant-based meat and dairy substitutes; PBWFs, plant-based whole foods; T2DM, type 2 diabetes mellitus; TLC, Therapeutic Lifesyle Change.

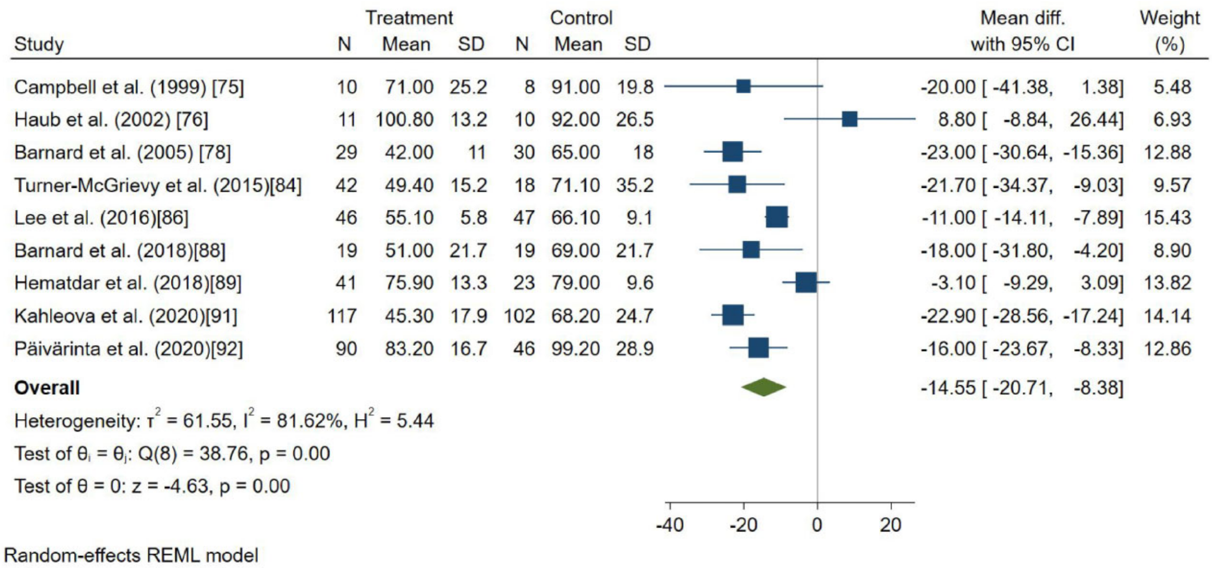

Figure 2 **Forest plot of protein intake (expressed in g/d) in participants who consumed a meat- and/or dairy-reduced diet compared with intake in those who consumed a habitual diet (rich in meat and/or dairy).** Data are presented as the mean difference (Mean diff) with 95%CI. Heterogeneity was quantified by I^2, and significance was considered at $P < 0.10$. The median duration of the studies was 12 weeks (range, 8–24). *Abbreviation*: REML, restricted maximal likelihood.

effect of pooled results (see Figure S3-A in the Supporting Information online). Subgroup analysis showed that the difference in protein intake was large when participants totally excluded meat and dairy (4 RCTs; MD, −18 g/d; 95%CI, −26 to −10; $I^2 = 83\%$) and when they simultaneously reduced both meat and dairy (6 RCTs; MD, −18 g/d; 95%CI, −24 to −12; $I^2 = 73\%$) (Table 3). Meta-regression revealed evidence of effect modification by both type of intervention and duration of study, where provision of behavioral intervention (β: −28 g/d, 95%CI, −56.5 to −1.0; $P = 0.042$) and long-term studies (β: −13 g/d; 95%CI, −20.40 to −5.5; $P = 0.001$) were associated with lower protein intake (see Table S4 in the Supporting Information online).

Exploratory meta-analysis revealed no difference in energy intake (11 RCTs; MD, −54 kcal/d; 95%CI, −112 to 4) between participants who consumed the meat and/or dairy-reduced diets and those who consumed control diets (see Figure S4 in the Supporting Information online). On the contrary, participants who reduced meat and/or dairy had a significantly lower fat intake (5 RCTs; MD, −6 g/d; 95%CI, −12.7 to −0.4) and a higher carbohydrate intake (MD, 33 g/d; 95%CI, 11 to 55) than those who consumed the meat- and/or dairy-rich diets (see Figures S5 and S6 in the Supporting Information online, respectively).

Effect of reducing meat and/or dairy on body weight

A total of 1045 participants from 14 RCTs contributed data to the meta-analysis of body weight (Figure 3[74–76,79–85,88,90,91]). The included RCTs had a median duration of 13 weeks (range, 4–24 weeks). There was no evidence of a significant impact on body weight (14 RCTs; MD, −1.2 kg; 95%CI, −3.0 to 0.7). Evidence of heterogeneity was low ($I^2 = 12\%$, $P = 0.31$). Systematic removal of individual studies did not alter the pooled effect results (see Figure S3-B in the Supporting Information online). Likewise, the exclusion of studies evaluated as having high risk of bias[75,85] did not change the overall effect size (12 RCTs; MD, −1.6 kg; 95%CI, −3.5 to 0.2; $I^2 = 12\%$; $P = 0.09$). Subgroup analysis shows that the difference in body weight was large when participants totally excluded meat and/or dairy (6 RCTs; MD, −2.7 kg; 95%CI, −5.0 to −0.5; $I^2 = 3\%$) and when the studies provided behavioral interventions (6 RCTs; MD, −2.4 kg; 95%CI, −4.5 to −0.3; $I^2 = 0\%$) (Table 3). Meta-regression revealed no evidence of effect modification (see Table S5 in the Supporting Information online).

Effect of reducing meat and/or dairy on BMI

A total of 820 participants from 13 RCTs contributed data to the meta-analysis of BMI, Figure 4.[75,78–80,82–88,90,91] The included RCTs had a median duration of 14 weeks (range, 6–24 weeks). There was no evidence of an impact on BMI (13 RCTs; MD, −0.3 kg/m^2; 95%CI, −1.1 to 0.4). Evidence of heterogeneity was moderate ($I^2 = 34\%$, $P = 0.16$). Systematic removal of individual studies did not alter pooled effect results (see Figure S3-C in the Supporting Information online). Similarly,

Table 3 **Mean differences in protein intake, body weight, body mass index, waist circumference, body fat, and lean body mass between the intervention and control groups, stratified by different subgroups according to intervention characteristics, profile of the participants, and ad hoc dietary restrictions**

Outcome	Variable	Subgroup	No. of RCTs per subgroup	Pooled MD (95%CI)	I^2 (%)	Within-group *P* value	Between-group *P* value
Protein intake (g/d)	Type of intervention	Dietary intervention	2	−4.9 (−29.1 to 19.2)	82	0.690	0.039
		Behavioral intervention	7	−16.0 (−22.7 to −9.3)	82	< 0.001	
	Degree of reduction	Partial reduction/substitution	5	−9.9 (−19.6 to −0.1)	69	0.005	0.180
		Total reduction/substitution	4	−18.4 (−26.2 to −10.6)	83	< 0.001	
	Single or double substitution of meat and/or dairy	Reduction of dairy only	0	N/A	N/A	N/A	0.030
		Reduction of meat only	3	−3.7 (−15.5 to 8.1)	52	0.540	
		Reduction of both meat and dairy	6	−18.2 (−24.1 to −12.2)	73	< 0.001	
	Health status of participants	Healthy volunteers/participants	6	−18.0 (−24.8 to −11.1)	57	< 0.001	0.070
		Volunteers diagnosed with chronic disease conditions	3	−9.1 (−16.0 to −2.3)	73	0.030	
	Age category	Middle-aged adults (< 55 y)	3	−20.9 (−25.5 to −16.2)	0	< 0.001	0.030
		Older adults (≥ 55 y)	6	−11.4 (−18.7 to −4.0)	79	0.002	
	Ad hoc dietary restrictions	Energy/calorie restriction	1	−18.0 (−31.8 to −4.2)	N/A	0.010	0.610
		Ad libitum energy or calorie consumption	8	−14.0 (−20.4 to −7.5)	82	< 0.001	
	Isocaloric comparison	Studies with isocaloric diets	1	−3.1 (−8.7 to 2.5)	N/A	0.280	0.002
		Studies without isocaloric diets	10	−16.4 (−22.4 to −10.4)	72	< 0.001	
	Type of food substitutes used	Traditional plant-based whole foods	7	−16.0 (−22.7 to −9.3)	82	< 0.001	0.390
		Novel plant-based meat and dairy substitutes	2	−4.9 (−29.1 to −19.2)	82	0.020	
	Cointervention	Studies with cointervention	7	−16.4 (−23.4 to −9.4)	76	< 0.001	0.031
		Studies without cointervention	2	−9.0 (−21.6 to 3.5)	82	0.160	
	Duration of studies	Short-term (≤ 12 wk)	5	−8.6 (−15.1 to −2.2)	68	0.001	< 0.001
		Long-term (> 12 wk)	4	−22.3 (−26.5 to −18.1)	0	< 0.001	
	Weight loss intention	Studies aimed at achieving weight loss	1	−21.7 (−38.6 to −4.8)	N/A	0.010	0.390
		Studies not aimed at achieving weight loss	8	−13.8 (−20.1 to −7.5)	82	< 0.001	
	Protein substitutes	Legumes only	5	−18.7 (−25.8 to −11.6)	78	< 0.001	0.130
		Legumes + animal foods	3	−5.2 (−16.7 to 6.2)	76	0.370	
		Nonlegume foods	1	−20.0 (−20.4 to −8.3)	N/A	0.060	
Body weight (kg)	Type of intervention	Dietary intervention	8	0.6 (−2.5 to 3.7)	18	0.710	0.120
		Behavioral intervention	6	−2.4 (−4.5 to −0.3)	0	0.020	
	Degree of reduction	Partial reduction/substitution	8	0.3 (−2.1 to 2.8)	3	0.760	0.070
		Total reduction/substitution	6	−2.7 (−5.0 to −0.4)	3	0.020	
	Single or double substitution of meat and/or dairy	Reduction of dairy only	3	−1.1 (−4.0 to 1.7)	0	0.440	0.900
		Reduction meat only	4	−0.0 (−4.1 to 3.9)	16	0.980	
		Reduction of both meat and dairy	7	−1.0 (−4.2 to 2.3)	38	0.560	

(continued)

Table 3 **Continued**

Outcome	Variable	Subgroup	No. of RCTs per subgroup	Pooled MD (95%CI)	I^2 (%)	Within-group *P* value	Between-group *P* value
	Health status of participants	Healthy participants/ volunteers	8	−1.0 (−3.3 to 1.3)	31	0.390	0.990
		Volunteers diagnosed with chronic disease conditions	6	−1.0 (−4.9 to 2.8)	11	0.590	
	Age category	Middle-aged adults (< 55 y)	9	−1.3 (−3.8 to 1.1)	38	0.300	0.490
		Older adults (≥ 55 y)	5	0.2 (−3.4 to 3.8)	0	0.900	
	Ad hoc dietary restrictions	Energy/calorie restriction	6	−1.1 (−4.5 to 1.7)	4	0.380	0.780
		Ad libitum energy or calorie consumption	8	−0.8 (−3.4 to 1.7)	34	0.530	
	Isocaloric comparison	Studies with isocaloric diets	1	1.1 (−6.1 to 8.3)	N/A	0.760	0.540
		Studies without isocaloric diets	13	−1.2 (−3.2 to 0.8)	22	0.240	
	Type of food substitutes used	Traditional plant-based whole foods	12	−1.1 (−3.4 to 1.2)	29	0.350	0.760
		Novel plant-based meat and dairy substitutes	2	−0.4 (−4.2 to 3.3)	0	0.830	
	Cointervention	Studies with cointervention	9	−0.7 (−3.4 to 1.9)	27	0.570	0.800
		Studies without cointervention	5	−1.3 (−4.2 to 1.6)	19	0.390	
	Duration of studies	Short-term (≤ 12 wk)	7	−0.1 (−2.4 to 2.2)	0	0.920	0.370
		Long-term (> 12 wk)	7	−1.9 (−5.0 to 1.2)	35	0.240	
	Weight loss intentions	Studies aimed at achieving weight loss	8	0.6 (−2.5 to 3.7)	18	0.710	0.120
		Studies not aimed at achieving weight loss	6	−2.4 (−4.5 to −0.3)	0	0.020	
	Protein substitution sources	Legumes only	5	−2.3 (−5.8 to 1.1)	22	0.190	0.580
		Legumes + animal foods	4	0.1 (−2.8 to 3.1)	0	0.940	
		Nonlegume foods	5	−1.0 (−4.6 to 2.6)	28	0.590	
BMI (kg/m^2)	Type of intervention	Dietary intervention	4	−0.5 (−1.6 to 0.4)	0	0.280	0.590
		Behavioral intervention	9	−0.1 (−1.2 to 0.9)	50	0.780	
	Degree of reduction	Partial reduction/substitution	7	−0.0 (−0.9 to 0.8)	0	0.880	0.440
		Total reduction/substitution	6	−0.6 (−2.0 to 0.6)	57	0.320	
	Single or double substitution of meat and/ or dairy	Reduction of dairy only	1	−1.1 (−3.4 to 1.2)	N/A	0.460	0.760
		Reduction of meat only	3	0.0 (−1.8 to 1.8)	41	0.980	
		Reduction of both meat and dairy	9	−0.3 (−1.3 to 0.5)	41	0.460	
	Health status of participants	Healthy volunteers/ participants	5	−0.7 (−2.1 to 074)	49	0.320	0.340
		Volunteers diagnosed with chronic disease conditions	8	0.0 (−0.6 to 0.7)	0	0.880	
	Age category	Middle-aged adults (< 55 y)	7	−0.4 (−1.6 to 0.7)	51	0.460	0.480
		Older adults (≥ 55 y)	6	0.0 (−0.7 to 0.9)	0	0.880	
	Ad hoc dietary restrictions	Energy/calorie restriction	6	−0.1 (−1.0 to 0.8)	0	0.820	0.570
		Ad libitum energy or calorie consumption	7	−0.5 (−1.7 to 0.6)	52	0.370	

(continued)

Table 3 **Continued**

Outcome	Variable	Subgroup	No. of RCTs per subgroup	Pooled MD (95%CI)	I^2 (%)	Within-group *P* value	Between-group *P* value
	Isocaloric comparison	Studies with isocaloric diets	2	−0.5 (−2.2 to 1.2)	0	0.500	0.770
		Studies without isocaloric diets	11	−0.2 (−1.1 to 0.5)	40	0.510	
	Type of food substitutes used	Traditional plant-based whole foods	12	−0.2 (−1.0 to 0.5)	35	0.520	0.410
		Novel plant-based meat and dairy substitutes	1	0.1 (−3.6 to 1.0)	N/A	0.280	
	Cointervention	Studies with cointervention	11	−0.1 (−1.0 to 0.6)	392	0.690	0.260
		Studies without cointervention	2	−1.2 (−2.9 to 0.4)	0	0.140	
	Duration of studies	Short-term (≤ 12 wk)	6	0.1 (−0.6 to 0.9)	0	0.760	0.280
		Long-term (> 12 wk)	7	−0.6 (−1.8 to 0.5)	42	0.270	
	Weight loss intentions	Studies aimed at achieving weight loss	4	−0.4 (−1.5 to 0.6)	0	0.420	0.830
		Studies not aimed at achieving weight loss	9	−0.2 (−1.3 to 0.7)	46	0.590	
	Protein substitution sources	Legumes only	8	−0.2 (−1.4 to 0.8)	53	0.630	0.570
		Legumes + animal foods	2	0.1 (−1.3 to 1.7)	8	0.810	
		Nonlegume foods	3	−0.9 (−2.2 to 0.4)	0	0.190	
Waist circumference (cm)	Type of intervention	Dietary intervention	4	−1.1 (−3.6 to 1.4)	0	0.390	0.640
		Behavioral intervention	5	−0.1 (−3.3 to 3.1)	51	0.950	
	Degree of reduction	Partial reduction/substitution	6	−0.45 (−3.5 to 2.6)	45	0.770	0.910
		Total reduction/substitution	3	−0.6 (−3.1 to 1.7)	0	0.590	
	Single or double substitution of meat and/or dairy	Reduction of dairy only	2	−3.5 (−11.0 to 4.0)	73	0.360	0.220
		Reduction meat only	1	−3.0 (−7.3 to 1.3)	N/A	0.170	
		Reduction of both meat and dairy	6	−0.6 (−1.4 to 2.7)	0	0.540	
	Health status of participants	Healthy volunteers/participants	5	−0.7 (−3.3 to 1.8)	40	0.560	0.710
		Volunteers diagnosed with chronic disease conditions	6	−1.4 (−3.5 to 0.7)	25	0.200	
	Age category	Middle-aged adults (< 55 y)	6	−0.6 (−3.6 to 2.9)	50	0.660	0.770
		Older adults (≥ 55 y)	3	−0.0 (−2.8 to 2.6)	0	0.950	
	Ad hoc dietary restrictions	Energy/calorie restriction	4	−1.9 (−5.4 to 1.4)	45	0.260	0.250
		Ad libitum energy or calorie consumption	5	0.4 (−1.7 to 2.5)	0	0.690	
	Isocaloric comparison	Studies with isocaloric diets	2	−0.0 (−4.0 to 4.1)	4	0.970	0.770
		Studies without isocaloric diets	8	−0.6 (−2.9 to 1.7)	38	0.590	
	Type of food substitutes used	Traditional plant-based whole foods	7	−0.3 (−2.9 to 2.1)	42	0.760	0.840
		Novel plant-based meat and dairy substitutes	2	−0.8 (−4.1 to 2.5)	0	0.630	
	Cointervention	Studies with cointervention	6	0.6 (−1.4 to 2.7)	0	0.540	0.110
		Studies without cointervention	3	−2.9 (−6.7 to 0.9)	47	0.140	

(continued)

Table 3 **Continued**

Outcome	Variable	Subgroup	No. of RCTs per subgroup	Pooled MD (95%CI)	I^2 (%)	Within-group *P* value	Between-group *P* value
	Duration of studies	Short-term (≤ 12 wk)	5	−0.8 (−3.5 to 1.7)	31	0.510	0.660
		Long-term (> 12 wk)	4	0.0 (−3.3 to 3.4)	40	0.960	
	Weight loss intentions	Studies aimed at achieving weight loss	4	−1.4 (−6.2 to 3.4)	65	0.570	0.550
		Studies not aimed at achieving weight loss	5	0.1 (−1.8 to 2.2)	0	0.870	
	Protein substitution sources	Legumes only	5	0.1 (−1.9 to 2.3)	0	0.890	0.120
		Legumes + animal foods	2	2.5 (−4.1 to 9.1)	62	0.460	
		Nonlegume foods	2	−4.7 (−2.4 to 1.4)	30	0.050	
Body fat (fat mass)	Type of intervention	Dietary intervention	4	0.0 (−2.1 to 2.2)	0	0.950	0.550
		Behavioral intervention	4	−1.3 (−5.2 to 2.6)	69	0.520	
	Degree of reduction	Partial reduction	7	−0.0 (−1.7 to 1.7)	0	0.970	0.005
		Total reduction	1	−4.5 (−7.0 to −1.9)	N/A	< 0.001	
	Single or double substitution of meat and/or dairy	Reduction of dairy only	1	−3.9 (−8.7 to 0.9)	N/A	0.120	0.240
		Reduction of meat only	3	0.6 (−1.7 to 2.9)	0	0.590	
		Reduction of both meat and dairy	4	−1.0 (−4.8 to 2.8)	63	0.600	
	Health status of participants	Healthy volunteers	5	−0.1 (−3.4 to 3.2)	68	0.940	0.440
		Volunteers diagnosed with chronic disease conditions	3	−1.8 (−4.7 to 0.9)	0	0.200	
	Age category	Middle-aged adults (< 55 y)	6	−1.2 (−3.9 to 1.3)	58	0.350	0.400
		Older adults (≥ 55 y)	2	0.7 (−2.9 to 4.3)	0	0.710	
	Ad hoc dietary restrictions	Energy/calorie restriction	4	−0.7 (−2.7 to 1.3)	0	0.500	0.810
		Ad libitum energy or calorie consumption	4	−0.1 (−4.5 to 4.3)	70	0.960	
	Isocaloric comparison	Studies with isocaloric diets	2	0.3 (−2.2 to 2.9)	0	0.810	0.420
		Studies without isocaloric diets	6	−1.2 (−4.1 to 1.5)	53	0.390	
	Type of food substitutes used	Traditional plant-based whole foods	7	−1.0 (−3.6 to 1.3)	54	0.400	0.650
		Novel plant-based meat and dairy substitutes	1	0.7 (−6.3 to 7.7)	N/A	0.410	
	Cointervention	Studies with cointervention	6	−0.6 (−3.5 to 2.1)	52	0.640	0.830
		Studies without cointervention	2	−1.2 (−5.5 to 3.1)	58	0.580	
	Duration of studies	Short-term (≤ 12 wk)	5	−0.2 (−2.1 to 1.7)	0	0.800	0.820
		Long-term (> 12 wk)	3	−0.9 (−6.1 to 4.3)	72	0.740	
	Weight loss intentions	Studies aimed at achieving weight loss	5	−0.1 (−2.7 to 2.4)	24	0.910	0.450
		Studies not aimed at achieving weight loss	3	−1.8 (−5.3 to 1.7)	61	0.320	
	Protein substitution sources	Legumes only	2	−3.0 (−6.8 to 0.8)	53	0.130	0.340
		Legumes + animal foods	3	1.0 (−2.9 to 5.0)	17	0.600	
		Nonlegume foods	3	−0.4 (−3.0 to 2.1)	24	0.740	

(continued)

Table 3 **Continued**

Outcome	Variable	Subgroup	No. of RCTs per subgroup	Pooled MD (95%CI)	I^2 (%)	Within-group *P* value	Between-group *P* value
Lean body mass (fat-free mass)	Type of intervention	Dietary intervention	4	−0.7 (−2.7 to 1.2)	0	0.490	0.710
		Behavioral intervention	5	−0.2 (−1.7 to 1.3)	01	0.750	
	Degree of reduction	Partial reduction/substitution	7	−0.3 (−2.1 to 1.3)	0	0.680	09590
		Total reduction/substitution	2	−0.4 (−2.0 to 1.1)	0	0.700	
	Single or double substitution of meat and/or dairy	Reduction of dairy only	1	−4.8 (−14.1 to 4.5)	N/A	0.310	0.590
		Reduction of meat only	3	−0.6 (−2.7 to 1.3)	0	0.510	
		Reduction of both meat and dairy	5	−0.1 (−1.6 to 1.3)	0	0.850	
	Health status of participants	Healthy volunteers/participants	6	−0.3 (−1.6 to 0.8)	0	0.530	0.980
		Volunteers diagnosed with chronic disease conditions	3	−0.4 (−4.3 to 3.4)	0	0.820	
	Age category	Middle-aged adults (< 55 y)	6	−0.4 (−1.8 to 0.9)	0	0.530	0.880
		Older adults (≥ 55 y)	3	−0.2 (−2.3 to 1.8)	0	0.800	
	Ad hoc dietary restrictions	Energy/calorie restriction	4	−0.8 (−3.0 to 1.3)	0	0.460	0.650
		Ad libitum energy or calorie consumption	5	−0.2 (−1.6 to 1.1)	0	0.760	
	Isocaloric comparison	Studies with isocaloric diets	2	−0.6 (−3.0 to 1.7)	0	0.610	0.840
		Studies without isocaloric diets	7	−0.3 (−1.6 to 1.0)	0	0.630	
	Type of food substitutes used	Traditional plant-based whole foods	8	−0.3 (−1.5 to 0.8)	0	0.580	0.740
		Novel plant-based meat and dairy substitutes	1	−1.1 (−5.4 to 3.2)	N/A	0.6200	
	Cointervention	Studies with cointervention	8	−0.3 (−1.5 to 0.8)	0	0.590	0.350
		Studies without cointervention	1	−4.8 (−14.1 to 4.5)	N/A	0.310	
	Duration of studies	Short-term (≤ 12 wk)	5	−0.6 (−2.5 to 1.2)	0	0.500	0.740
		Long-term (> 12 wk)	4	−0.2 (−1.7 to 1.2)	0	0.760	
	Weight loss intentions	Studies aimed at achieving weight loss	5	−0.7 (−2.7 to 1.2)	0	0.460	0.660
		Studies not aimed at achieving weight loss	4	−0.2 (−1.67 to 1.2)	0	0.780	
	Protein substitution sources	Legumes only	3	−0.3 (−1.8 to 1.2)	0	0.690	0.890
		Legumes + animal foods	3	0.0 (−3.1 to 3.2)	0	0.960	
		Nonlegume foods	3	−0.8 (−3.0 to 1.4)	0	0.470	

Abbreviations: BMI, body mass index; MD, mean difference; NA, not available.

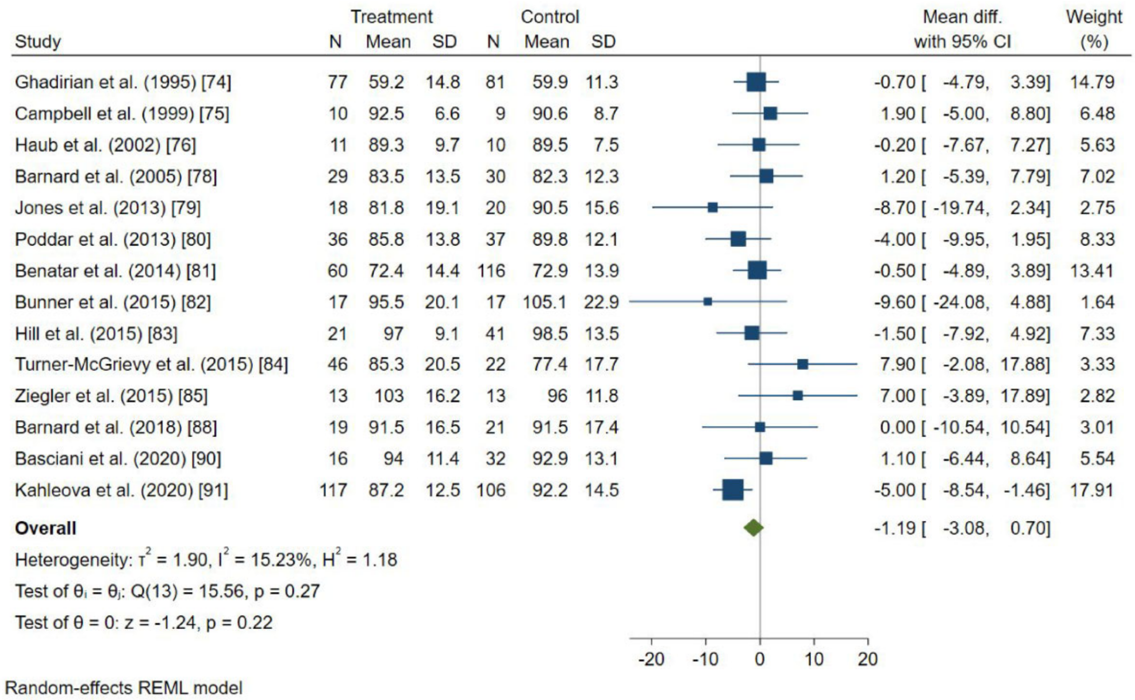

Figure 3 **Forest plot of body weight (expressed in kg) of participants who consumed a meat- and/or dairy-reduced diet compared with body weight of those who consumed a habitual diet (rich in meat and/or dairy).** Data are presented as the mean difference (Mean diff) with 95%CI. Heterogeneity was quantified by I^2, and significance was considered at $P < 0.10$. The median duration of the studies was 13 weeks (range, 4–24). *Abbreviation*: REML, restricted maximal likelihood.

exclusion of the studies evaluated as having high risk of bias[75,85,87] did not change the overall results (11 RCTs; MD, −0.4 kg/m^2; 95%CI, −1.3 to 0.4; $I^2 = 36$). Results of subgroup analysis are presented in Table 2. There was no difference between subgroups. Meta-regression revealed no evidence of effect modification (see Table S6 in the Supporting Information online).

Effect of reducing meat and/or dairy on waist circumference

A total of 652 participants from 9 RCTs contributed data to the meta-analysis of waist circumference (Figure 5[78–81,83,84,86,87,90]).The included RCTs had a median duration of 12 weeks (range, 4–24 weeks). There was no evidence of an impact on waist circumference (9 RCTs; MD, −0.5 cm; 95%CI, −2.1 to 1.1). Evidence of heterogeneity was low ($I^2 = 26\%$, $P = 0.21$). Systematic removal of individual studies did not alter pooled effect results (see Figure S3-E in the Supporting Information online). Similarly, exclusion of the study evaluated as having high risk of bias[87] did not change the overall results (MD, −0.3 cm; 95%CI, −2.4 to 1.7; $I^2 = 32$). Results of subgroup analysis are presented in Table 3. There was no difference between subgroups. Meta-regression revealed no evidence of effect modification (see Table S7 in the Supporting Information online).

Effect of reducing meat and/or dairy on body fat (fat mass)

A total of 579 participants from 8 RCTs contributed data to the meta-analysis of body fat (Figure 6[75–77,79,83,84,90,91]). The included RCTs had a median duration of 12 weeks (range, 6–24 weeks). There was no evidence of an impact on body fat (8 RCTs; MD, −1.0 kg; 95%CI, −3.0 to 1.0). Evidence of heterogeneity was moderate ($I^2 = 48\%$, $P = 0.50$). Systematic removal of individual studies did not alter pooled effect results (see Figure S3-D in the Supporting Information online). The exclusion of the study evaluated as having high risk of bias[75] did not change the overall results (MD, −1.1 kg; 95%CI, −3.5 to 1.1; $I^2 = 51$). Results of the subgroup analysis are presented in Table 2. There was no difference between subgroups. Moreover, meta-regression analyses revealed no evidence of effect modification (see Table S8 in the Supporting Information online).

Effect of reducing meat and/or dairy on lean body mass (fat-free mass)

A total of 638 participants from 9 RCTs contributed data to the meta-analysis of lean body mass (Figure 7[75–79,83,84,90,91]). The included RCTs had a median duration

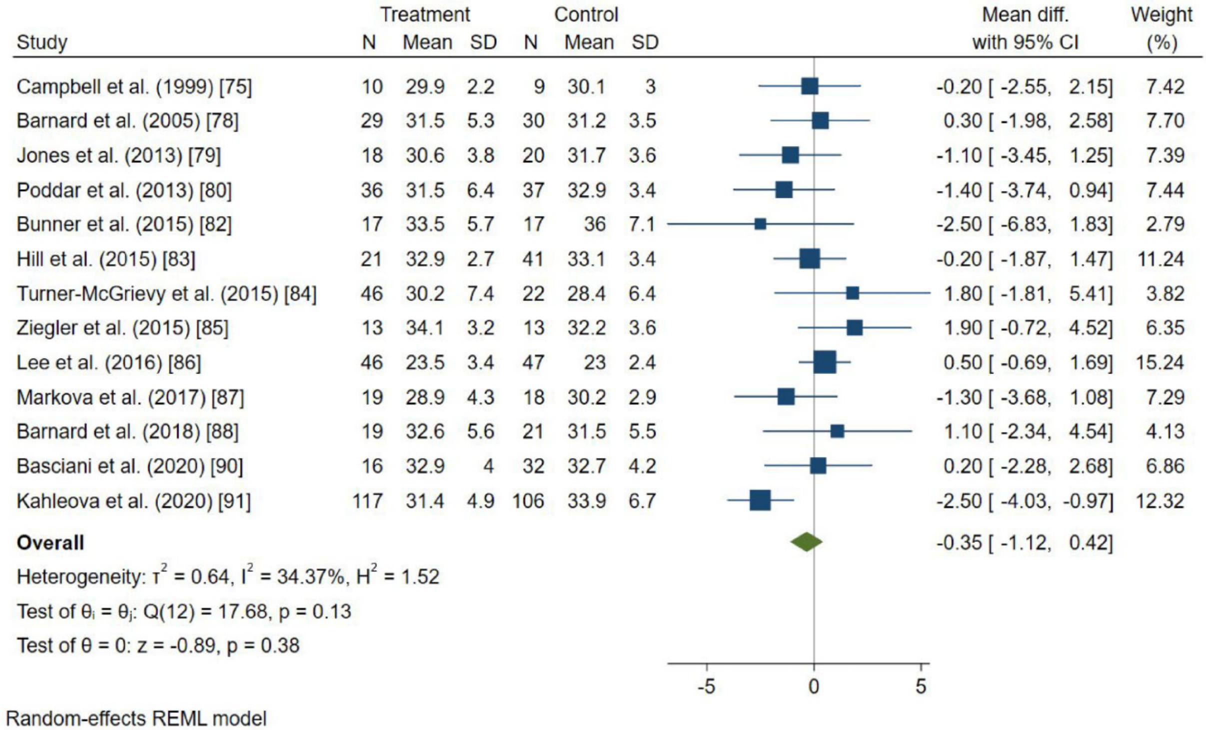

Figure 4 **Forest plot of body mass index (expressed in kg/m²) of participants who consumed a meat- and/or dairy-reduced diet compared with body mass index of those who consumed a habitual diet (rich in meat and/or dairy).** Data are presented as the mean difference (Mean diff) with 95%CI. Heterogeneity was quantified by I^2, and significance was considered at $P < 0.10$. The median duration of the studies was 14 weeks (range, 6–24). *Abbreviation*: REML, restricted maximal likelihood.

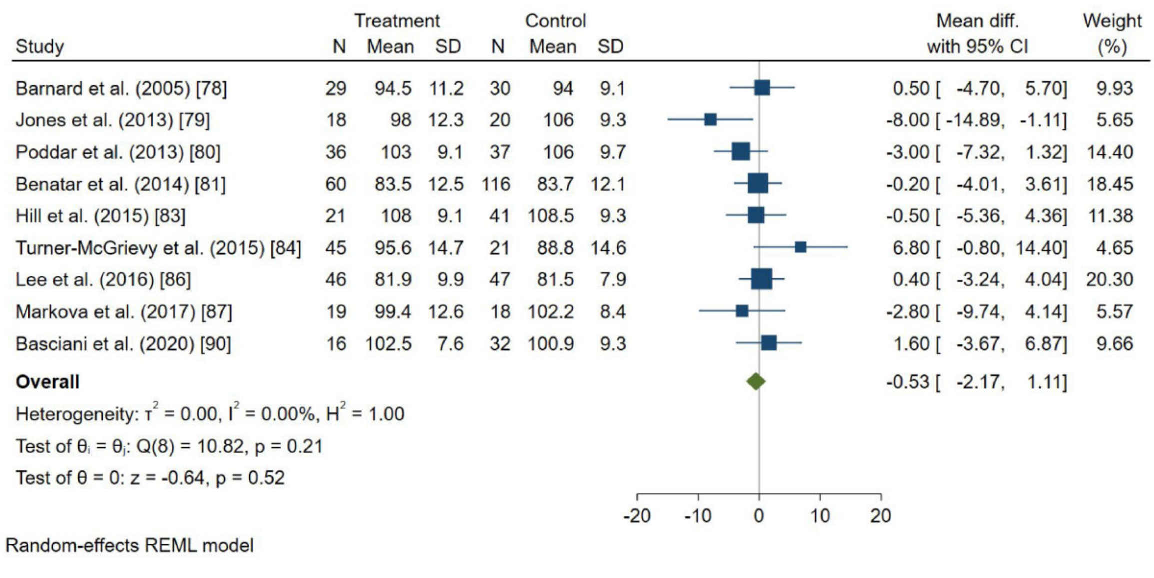

Figure 5 **Forest plot of waist circumference (expressed in cm) of participants who consumed a meat- and/or dairy-reduced diet compared with waist circumference of those who consumed a habitual diet (rich in meat and/or dairy).** Data are presented as the mean difference (Mean diff) with 95%CI. Heterogeneity was quantified by I^2, and significance was considered at $P < 0.10$. The median duration of the studies was 12 weeks (range, 4–24). *Abbreviation*: REML, restricted maximal likelihood.

of 12 weeks (range, 6–24 weeks). There was no evidence of an impact on lean body mass (9 RCTs; MD, −0.4 kg; 95%CI, −1.5 to 0.7). There was no evidence of heterogeneity ($I^2 = 0\%$, $P = 0.91$). Systematic removal of individual studies did not alter pooled effect results (see Figure S3-F in the Supporting Information online). The

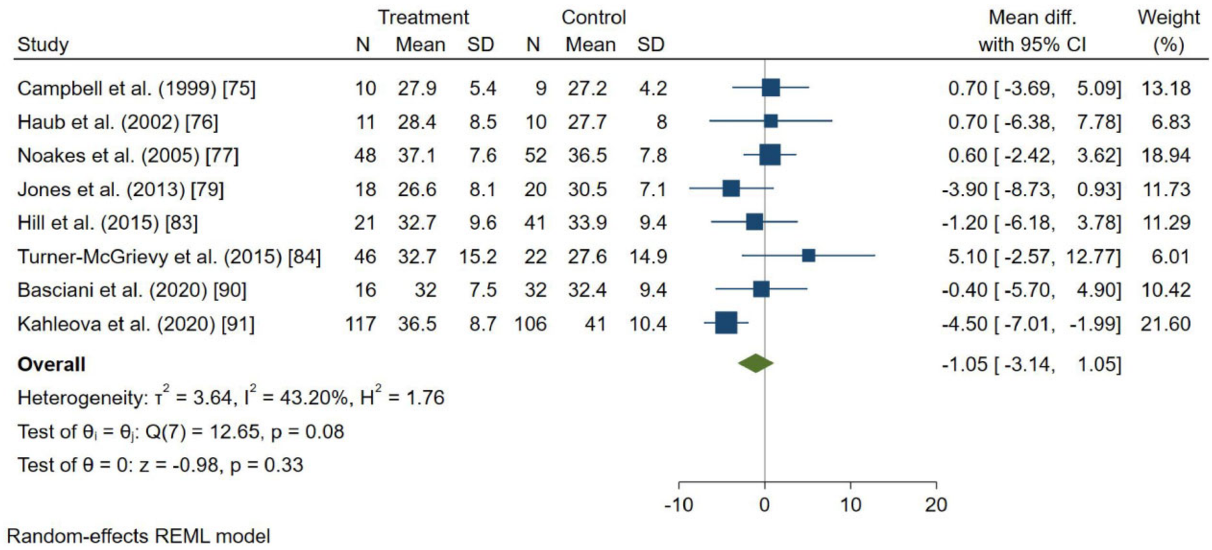

Figure 6 **Forest plot of body fat (expressed in kg) in participants who consumed a meat- and/or dairy-reduced diet compared with body fat in those who consumed a habitual diet (rich in meat and/or dairy).** Data are presented as the mean difference (Mean diff) with 95%CI. Heterogeneity was quantified by I^2, and significance was considered at $P < 0.10$. The median duration of the studies was 12 weeks (range, 6–24). *Abbreviation*: REML, restricted maximal likelihood.

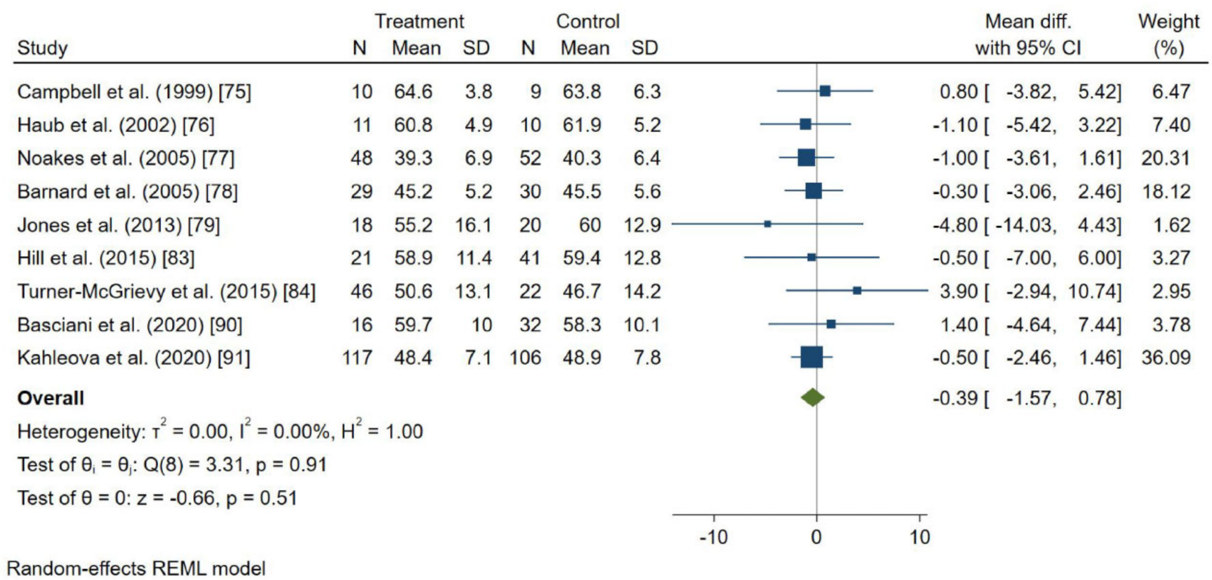

Figure 7 **Forest plot of lean body mass (expressed in kg) in participants who consumed a meat- and/or dairy-reduced diet compared with lean body mass in those who consumed a habitual diet (rich in meat and/or dairy).** Data are presented as the mean difference (Mean diff) with 95%CI. Heterogeneity was quantified by I^2, and significance was considered at $P < 0.10$. Median duration of the studies was 12 weeks (range, 6–24). *Abbreviation*: REML, restricted maximal likelihood.

exclusion of the study evaluated as having high risk of bias[75] also did not change the overall results (MD, −0.4 kg; 95%CI, −1.7 to 0.7). Results of the subgroup analysis are presented in Table 2. There was no difference between subgroups. Meta-regression also revealed no evidence of effect modification (see Table S9 in the Supporting Information online).

DISCUSSION

This review evaluated randomized controlled studies investigating the effects of reducing meat and/or dairy consumption on protein intake, anthropometric measurements, and body composition in predominantly middle-aged and older adults with BMIs > 24 kg/m^2 from affluent regions in the world. The main finding was that consumption of meat- and/or dairy-reduced diets significantly reduced protein intake. There was no evidence of a significant impact on anthropometric measurements or body composition. However, although they were not significant, all measures of anthropometry (body weight, BMI, and waist circumference) and body composition (body fat and lean body mass) appear to be consistently lower among participants who consumed meat- and/or dairy-reduced diets than among those in the control group.

Protein intake

Pooled analysis showed that consumption of meat- and/or dairy-reduced diets reduced protein intake (−14 g/d). This amount of protein is estimated to be around 25% of current protein recommendations.[93] There was also a difference between partial and total reduction (or exclusion) of meat and/or dairy. Notably, reduction in protein intake was estimated to be around 15% and 30% when meat and/or dairy were partially and totally excluded, respectively. This magnitude of reduction appears to be plausible and consistent with earlier findings from observational studies on the impact of replacing meat and dairy on protein intake.[24,94]

Earlier reviews of observational studies have also shown that vegans had a lower protein intake than other groups who consumed animal foods.[56,95] Another review on diet quality reported that nonvegetarians have a higher intake of protein foods than vegetarians.[96] In this review, the prevalence of inadequate protein intake was estimated at 27%.[95] Likewise, Lederer et al[97] found that vegans had a lower protein intake (79 g) than individuals who consumed a meat-rich diet (112 g) in a 4-week randomized trial. In a cross-sectional study, elderly Chinese individuals had a lower protein intake than meat eaters.[98] In contrast, in a cross-sectional study, protein and carbohydrate intakes were shown to be higher in vegetarian than in nonvegetarian adolescents.[99]

The greatest point of contention is that meat- and/or dairy-reduced diets, such as vegan and vegetarian diets, supply sufficient protein. This point of view is based on high protein intakes in affluent societies.[100–102] Yet even in affluent societies there are population groups, including older adults and the elderly, who have lower protein intake than the general population.[103] Low protein intake has been reported in older people from different countries, including the United States,[104] the Netherlands,[105] Finland,[106] and Ireland.[107] Therefore, it is highly unlikely that the reduction in protein intake would be evenly distributed in different population groups, and this would then put individuals with already low habitual protein intake at risk of insufficient protein intake.

Protein adequacy was beyond the scope of this review. However, some population groups, including older adults and the elderly, require a high amount of protein, and any reduction in protein intake is a great concern in this population.[102,108] Indeed, among those who consume plant-based diets, protein intake has been shown to be more affected in older than in younger populations.[40,51] In a modeling study, Houchins et al[24] found that replacing meat and dairy with plant-based foods reduces 20% of the usual protein intake in the older population in the United States.

Moreover, substituting meat and dairy implies that most of the dietary proteins will be derived from plant-based foods,[86,87,92] yet plant-based foods usually supply lower-quality proteins than animal-sourced foods.[109,110] This may have both negative and positive effects on health, depending on the degree of reduction (partial or total) and the type of foods used to replace meat and/or dairy. Partially reducing meat and dairy will not largely affect the quality of proteins, as this implies that these products will be consumed in moderation and their proteins will complement the plant-based proteins.[111] On the other hand, in diets in which meat and dairy are totally excluded, the supply of high-quality dietary proteins will depend on the availability, accessibility, and selection of other protein-rich foods.

The certainty of the evidence was graded as moderate because of high heterogeneity, which persisted in subgroup analyses. Heterogeneity exploration suggested that variation in the effect could be attributed to differences in the age of participants and the duration of studies. Additionally, subgroup analysis also revealed the importance of comparing isocaloric diets. Of note, the difference in protein intake was small and nonsignificant in studies with isocaloric diets (MD, −3 g/d; 95%CI, −8 to 2), whereas it was large and significant in studies that did not compare isocaloric diets (MD, −16 g/d; 95%CI, −22 to −10).

Anthropometric measurements

Pooled analysis showed that reducing meat and/or dairy consumption had no significant impact on body weight, BMI, or waist circumference. Subgroup analysis also suggested there was no effect modification from different variables that were tested. The quality of the evidence was graded as low for body weight because of evidence of moderate heterogeneity and as moderate for BMI and waist circumference.

Contrary to the findings of this review, most of the available evidence favors that meat-reduced diets are associated with lower body weight.[57,112,113] A meta-analysis of intervention studies showed that a healthy Nordic diet, which is rich in plant-based foods and limited in meat and dairy, was associated with weight loss.[114] Another meta-analysis of 12 RCTs that compared vegetarian diets (vegan or lacto-ovo-vegetarian) with nonvegetarian diets found that consumption of vegetarian diets significantly reduced body weight over the course of 18 weeks.[59] That meta-analysis also noted that weight loss was more pronounced in those who consumed vegan diets than in those who adhered to lacto-ovo-vegetarian diets.[59] The present review noted a similar pattern in which mean differences in protein intake and body weight were significantly large when meat and/or dairy were totally excluded vs partially reduced. These findings suggest that the degree of impact may depend on the extent of reduction and the type of animal foods withdrawn from the diet.

Several studies have reported mixed findings with inconclusive evidence on the association between meat- and/or dairy-reduced diets and BMI and waist circumference.[115–117] A cohort study found that vegetarian women had a significantly lower waist circumference and BMI than women who consumed meat.[57] Moreover, it also found an association between frequency of meat consumption and high BMI and waist circumference.[57] Similarly, a narrative review of 22 studies (12 RCTs: 1 nonrandomized trial, 1 comparative study, and 8 cross-sectional studies) reported that consumption of vegan or vegetarian diets was associated with low weight and BMI.[118] In a randomized trial, participants who were assigned to consume low-fat plant-based diets showed a significant decrease in BMI compared with the control group at 6 and 12 months of follow-up.[119] Those in the intervention group were advised to consume whole grains, legumes, vegetables, and fruits while avoiding processed and fat-containing foods (nuts and avocado).[119] Conversely, a recent meta-analysis of 6 cross-sectional and 6 cohort studies did not find an association between high scores for consumption of plant-based foods and BMI or waist circumference.[120] That review, however, focused on the impact of increasing plant-based foods in the diet, regardless of whether animal foods were excluded.[120]

Body composition

Pooled analysis showed no significant impact of reduced meat and/or dairy consumption on body fat or lean body mass. Subgroup analysis also suggested there was no effect modification from different variables that were tested. The certainty of the evidence was graded as low for body fat, owing to moderate evidence of heterogeneity, and moderate for lean body mass.

Body composition change is one of the most discussed topics in relation to protein transition.[121–124] So far, mixed findings have been published, but most evidence shows that reduction of meat and dairy is associated with lower body fat and reduced lean muscle mass.[118,125] Of note, a narrative review that included 9 cross-sectional studies and 6 RTCs found that consumption of plant-based diets was negatively associated with lean muscle mass.[124] In an intervention study, participants assigned to eat meat only once a week and to exclude dairy products showed lower muscle mass and percentage of body fat than those who sustained their dietary habits after 10 weeks of follow-up.[112] Conversely, a meta-analysis reported no difference in absolute lean muscle mass between participants who consumed protein from animal foods and those who consumed plant-based proteins.[126] In that meta-analysis, however, plant-based foods were supplemented with soy protein.[126]

Low energy density from plant-based foods has been linked with a decrease in body fat.[127,128] Unlike reduction in body fat, however, reduction in lean body mass is not desirable. In the present review, reduction of meat and/or dairy consumption did not significantly reduce total energy intake, but this may be explained in part by a shift in macronutrients toward high carbohydrate intake. This shift in macronutrient intake to balance total energy intake warrants further exploration in future meta-analyses.

STRENGTHS AND LIMITATIONS

This review employed the concept of "meat and/or dairy reduction" to investigate the impact of meat and dairy consumption on protein intake, anthropometric measurements, and body composition. This concept was used to overcome health awareness issues that prevail in most vegetarian-omnivore comparisons.[129] In the present review, studies were eligible regardless of the health or disease status of participants, making these findings potentially relevant for both healthy populations and patients with underlying conditions. This review also has some limitations. First, data extraction was not performed in duplicate, which can be considered a limitation. However, two other authors independently checked the extracted data, thus ensuring that all pertinent data were retrieved. A second limitation is the relatively short duration of the included studies, which prevented the long-term effects of meat- and/or dairy-reduced diets on long-term outcomes (eg, morbidity and mortality) from being determined. A third limitation is the large variation in the amount of meat and dairy allowed for consumption between the interventional diets. This lack of standardization may have contributed to the variation of the effects observed in this review. Additionally, this review noted an inconsistency of change in energy intake and concurrent change in carbohydrate intake, which could have led to a higher energy intake. However, these small changes are difficult to show in a meta-analysis not based on individual data. Lastly, most of the trials (89%) enrolled individuals with BMIs > 24 kg/m^2 from Europe, North America, Australia, and New Zealand. Therefore, these findings cannot be generalized to the population-rich nations in the Global South.

CONCLUSION

Reduction of meat and/or dairy intake appears to significantly reduce protein intake. There is no evidence of a significant impact on anthropometric measurements or body composition. The overall quality of evidence in this systematic review was graded as low to moderate. More long-term intervention studies with defined amounts of meat and dairy intake are needed to investigate the medium- and long-term effects of reducing meat and/or dairy on nutrient intake, protein quality, body composition, anthropometric measurements, and long-term health outcomes.

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Author contributions. T.H., J.D., I.M.S.E., I.E.M., and M.K. conceptualized the review. T.H., together with E.E., performed the literature search and screening. T.H. extracted the data, performed statistical analyses, and interpreted the data. J.D. and I.M.S.E. independently checked the extracted data and supervised the analysis and interpretation. T.H. prepared the first draft of the manuscript. J.D., I.M.S.E., I.E.M., and M.K. revised and contributed to the subsequent versions of the manuscript. All authors read and approved the final version of the submitted manuscript.

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Supporting Information

The following Supporting Information is available through the online version of this article at the publisher's website.

Appendix S1 **PRISMA 2020 checklist.**

Table S1 **Search terms and process.**

Table S2 **Risk-of-bias assessment across 5 domains.**

Table S3 **Evidence quality assessment scores for the main outcomes of the review (protein intake, body weight, body mass index, body fat, and lean body mass), based on the NutriGrade scoring system for randomized controlled trials**.

Table S4 **Multivariable meta-regression with the mean difference in protein intake (g/d) as a dependent variable. Meta-regression included 9 randomized controlled trials, and the adjusted model included 6 covariates**.

Table S5 **Multivariable meta-regression with the mean difference in body weight (kg) as a dependent variable. Meta-regression included 14 randomized controlled trials, and the adjusted model included 7 covariate**s.

Table S6 **Multivariable meta-regression with the mean difference in body mass index (kg/m^2) as a dependent variable. Meta-regression included 13 randomized controlled trials, and the adjusted model included 7 covariates**.

Table S7 **Multivariable meta-regression with the mean difference in waist circumference (cm) as a dependent variable. Meta-regression included 9 randomized controlled trials, and the adjusted model included 6 covariates**.

Table S8 **Multivariable meta-regression with the mean difference in body fat (kg) as a dependent variable. Meta-regression included 8 randomized controlled trials, and the adjusted model included 5 covariates**.

Table S9 **Multivariable meta-regression with the mean difference in lean body mass (kg) as a dependent variable. Meta-regression included 9 randomized controlled trials, and the adjusted model included 6 covariates**.

Figure S1 **Risk of bias across the included studies. Studies were assessed as "low risk of bias" if the overall study design and conduct had no substantial deviations that were likely to bias the true effect estimate, "unclear risk of bias" if sufficient information was not provided to assess the risk of bias, and "high risk of bias" if the design and conduct of the study was likely to have substantial influence on the true effect estimate**.

Figure S2 **Funnel plots assessing publication bias and the effect of small studies for (A) protein intake, (B) body weight, (C) body mass index, (D) waist circumference, (E) body fat, and (F) lean body mass. $P < 0.05$ indicates evidence of publication bias (or small study effect)**.

Figure S3 **Forest plots of sensitivity analysis with leave-one-out meta-analysis for (A) protein intake (g/**

d), (B) body weight, (C) body mass index (kg/m^2), (D) waist circumference (cm), (E) body fat (kg), and (F) lean body mass (kg). Results are expressed as mean difference (Mean diff) with 95%CI for remaining studies after excluding one study.

Figure S4 **Forest plot of the mean difference in energy intake (expressed in kcal/d) for individuals who consumed a meat- and/or dairy-reduced diet compared with individuals who consumed meat- and/or a dairy-rich diet. Data are presented as mean difference with 95%CI.**

Figure S5 **Forest plot of the mean difference (MD) in carbohydrate intake (expressed in g/d) for individuals who consumed a meat- and/or dairy-reduced diet compared with individuals who consumed a meat- and/or dairy-rich diet. Data are presented as mean difference with 95%CI.**

Figure S6 **Forest plot of the mean difference (MD) in fat intake (expressed in g/d) for individuals who consumed a meat- and/or dairy-reduced diet compared with individuals who consumed a meat- and/or dairy-rich diet. Data are presented as mean difference (MD) with 95%CI.**

Data availability

Data described in the manuscript, the codebook used for data collection, and the analytic code are available upon request.

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