Review

The effect of plant-based dietary patterns on blood pressure: a systematic review and meta-analysis of controlled intervention trials

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Objectives: The consumption of strict vegetarian diets with no animal products is associated with low blood pressure (BP). It is not clear whether less strict plant-based diets (PBDs) containing some animal products exert a similar effect. The main objective of this meta-analysis was to assess whether PBDs reduce BP in controlled clinical trials.

Methods: We searched Cumulative Index to Nursing and Allied Health Literature, Medline, Embase, and Web of Science to identify controlled clinical trials investigating the effect of PBDs on BP. Standardized mean differences in BP and 95% confidence intervals were pooled using a random effects model. Risk of bias, sensitivity, heterogeneity, and publication bias were assessed.

Results: Of the 790 studies identified, 41 clinical trials met the inclusion criteria (8416 participants of mean age 49.2 years). In the pooled analysis, PBDs were associated with lower SBP [Dietary Approach to Stop Hypertension −5.53 mmHg (95% confidence intervals −7.95,−3.12), Mediterranean −0.95 mmHg (−1.70,−0.20), Vegan −1.30 mmHg (−3.90,1.29), Lacto-ovo vegetarian −5.47 mmHg (−7.60,−3.34), Nordic −4.47 mmHg (−7.14,−1.81), high-fiber −0.65 mmHg (−1.83,0.53), high-fruit and vegetable −0.57 mmHg (−7.45,6.32)]. Similar effects were seen on DBP. There was no evidence of publication bias and some heterogeneity was detected. The certainty of the results is high for the lacto-ovo vegetarian and Dietary Approach to Stop Hypertension diets, moderate for the Nordic and Mediterranean diets, low for the vegan diet, and very low for the high-fruit and vegetable and high-fiber diets.

Conclusion: PBDs with limited animal products lower both SBP and DBP, across sex and BMI.

Keywords: blood pressure, hypertension, meta-analysis, nutrition, plant-based diet

Abbreviations: BP, blood pressure; CI, confidence intervals; DASH, Dietary Approach to Stop Hypertension; GBD, global burden of disease; IPCC, Intergovernmental Panel on Climate Change; PBD, plant-based diet; RCT, randomized controlled trial; SE, standard error

INTRODUCTION

The global burden of disease (GBD) study identified hypertension [high blood pressure (BP)] as the global number one risk factor for deaths and disability-adjusted life years [1]. Hypertension is accountable for the death of 9 million people worldwide every year [2], due to its contribution to a variety of causes of death, including coronary heart disease, stroke, chronic kidney disease, and aneurysms. Hypertension is estimated to contribute 49% of all coronary heart disease and 62% of all stroke events [3]. An estimated 1.13 billion people globally have hypertension [4].

The GBD study estimated that increased consumption of whole grains, vegetables, nuts and seeds, and fruit could save 1.7, 1.8, 2.5, and 4.9 million lives per year, respectively, through the beneficial effects on cardiovascular risk factors [2]. Some epidemiological evidence supports an inverse association between fruit and vegetable consumption and BP [5–8]. There is also evidence of a positive association between meat consumption and hypertension risk [9]. In addition, vegetarian individuals have lower observed rates of ischemic heart disease than meat and fish eaters [10].

Two meta-analyses have been published in the past few years. One estimated the effect of vegetarian diets on BP [11] in 32 observational studies (totaling 21 604 participants). Consumption of vegetarian diets was associated with a 6.9 mmHg (95% confidence interval 9.1–4.7) lower mean SBP and a 4.7 mmHg (6.3–3.1) lower mean DBP compared with the consumption of omnivorous diets. For more robust evidence, seven clinical trials (totalling 311 participants) were included in the analysis. In the clinical trials, consumption of vegetarian diets was associated with a 4.8 mmHg (6.6–3.1) reduction in mean SBP and

Journal of Hypertension 2020, 38:000–000

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Received 6 June 2020 **Revised** 1 July 2020 **Accepted** 1 July 2020

DOI:10.1097/HJH.0000000000002604

a 2.2 mmHg (3.5–1.0) reduction in mean DBP compared with the consumption of omnivorous diets. A second meta-analysis looked at the BP effect of vegan diets compared with less restrictive diets in 11 randomized controlled trials (RCTs) including 983 participants [12]. Vegan diets only reduced BP in participants with a baseline SBP more than 130 mmHg (−4.10 mmHg (−8.14 to −0.06) SBP and −4.01 mmHg (−5.97 to −2.05) DBP.

Since then, more controlled trials on the effect of plant-based diets (PBDs) on BP have been published. Therefore, our study undertook a more comprehensive systematic review and a meta-analysis of controlled clinical trials involving not only vegan and vegetarian, but also the Mediterranean diet, Dietary Approaches to Stop Hypertension (DASH) diet, and Nordic diet, PBDs that allow limited amount of animal products, to investigate whether complete eradication of animal products is necessary to achieve significant BP lowering effects.

METHODS

The systematic review and meta-analysis is reported in line with the Preferred Reporting Items for Systematic reviews and Meta-analyses guidelines for RCTs [13] and is registered with International Prospective Register of Systematic Reviews (CRD42019153716).

Search strategy and selection criteria

We performed a computerized systematic search to identify studies on the effect of PBDs on BP. On 14 June 2019 we searched the following electronic databases limited to RCTs or controlled trials published in the English language since the inception of each database: Cumulative Index to Nursing and Allied Health Literature (1961–2019), MEDLINE (1964–2019), Embase (1974–2019), and, Web of Science (1900–2019). We used 'plant-based diet' terms (PBD OR plant food OR 'plant food' OR vegetarian* OR vegetarian diet OR vegan* OR vegan diet OR Mediterranean diet OR Nordic diet OR high-fiber diet OR DASH diet OR semi-vegetarian OR flexitarian OR pescatarian OR prudent diet OR portfolio diet) in combination with 'blood pressure' terms (hypertension OR BP). The electronic search strategy is shown in the supplement (Supplementary Table S1, http://links.lww.com/HJH/B430).

Inclusion and exclusion criteria

For inclusion, studies had to fulfill the following criteria: first, original published article; second, age of participants at least 18 years; third, PBD as an intervention, defined as dietary patterns that support high consumption of fruits, vegetables, whole grains, legumes, nuts and seeds, and often limit the consumption of most or all animal products; fourth, collection of sufficient data to allow calculation of mean differences in SBP/DBP between individuals consuming a PBD and those consuming a referent or control diet; fifth, RCT or controlled trial study design.

Studies were excluded if multiple interventions were used; study samples overlapped; Plant-based controls were used or uncontrolled; only meeting abstracts or unpublished material available. There were no restrictions regarding sex, race, ethnicity, language, sample size, or publication date. If multiple published reports from the same study were available, we only included the one with the most up to date information regarding the outcome. When data were not readily available from published reports, we wrote to the authors to ask for the data.

Data extraction, risk of bias, and quality assessment

Two reviewers (J.G. and E.G.) independently extracted the data. Disagreements about the inclusion of studies were resolved by arbitration between coauthors. From a total of 1238 search records, 790 studies were identified after duplicates had been removed (Fig. 1). Title and abstract screening were performed using Covidence and resulted in the exclusion of 705 studies. Full-text evaluation of 85 studies identified 41 trials that had data suitable for meta-analysis. Relevant data included, data regarding SBP and DBP and variance measures; first authors surname, year of publication and country of origin; number of participants, study design and duration; baseline characteristics of study population, including mean age, sex (proportion of men), SBP, DBP, antihypertensive medication use, BMI, alcohol intake, and dietary data (type of intervention and control diets); and outcomes, including adjustment factors used for each analytic model. Mean values for baseline age, the proportion of men, SBP and DBP, BMI, and alcohol intake were calculated. We assessed the risk of bias associated with the method of random sequence generation, allocation concealment, blinding, selective reporting, loss to follow-up, and completeness of reporting outcome data. We graded the risk of bias as low, unclear, or high according to recognized criteria [14]. The certainty of the entire body of evidence was assessed using GRADE methodology [15].

Intervention

PBDs were defined as dietary patterns that support high consumption of fruits, vegetables, whole grains, legumes, nuts, and seeds, and often limit the consumption of most or all animal products. Dietary patterns that fall within this umbrella term include vegan, lacto-ovo vegetarian, DASH, healthy Nordic, Mediterranean, high-fiber, and high-fruit and vegetables (Table 1).

Population

Our study includes normotensive and hypertensive populations.

Outcome

The difference in SBP and DBP between PBD and comparator (control) after a period of intervention. Any method of BP measurement was included. The measurements were made by health professionals or by the participants if they were trained on how to do so properly.

Data synthesis and statistical analysis

The mean differences in SBP and DBP between groups consuming plant-based or comparison diets were synthesized, and the standard errors (SEs) were obtained. If the SE of the mean differences was not supplied, it was

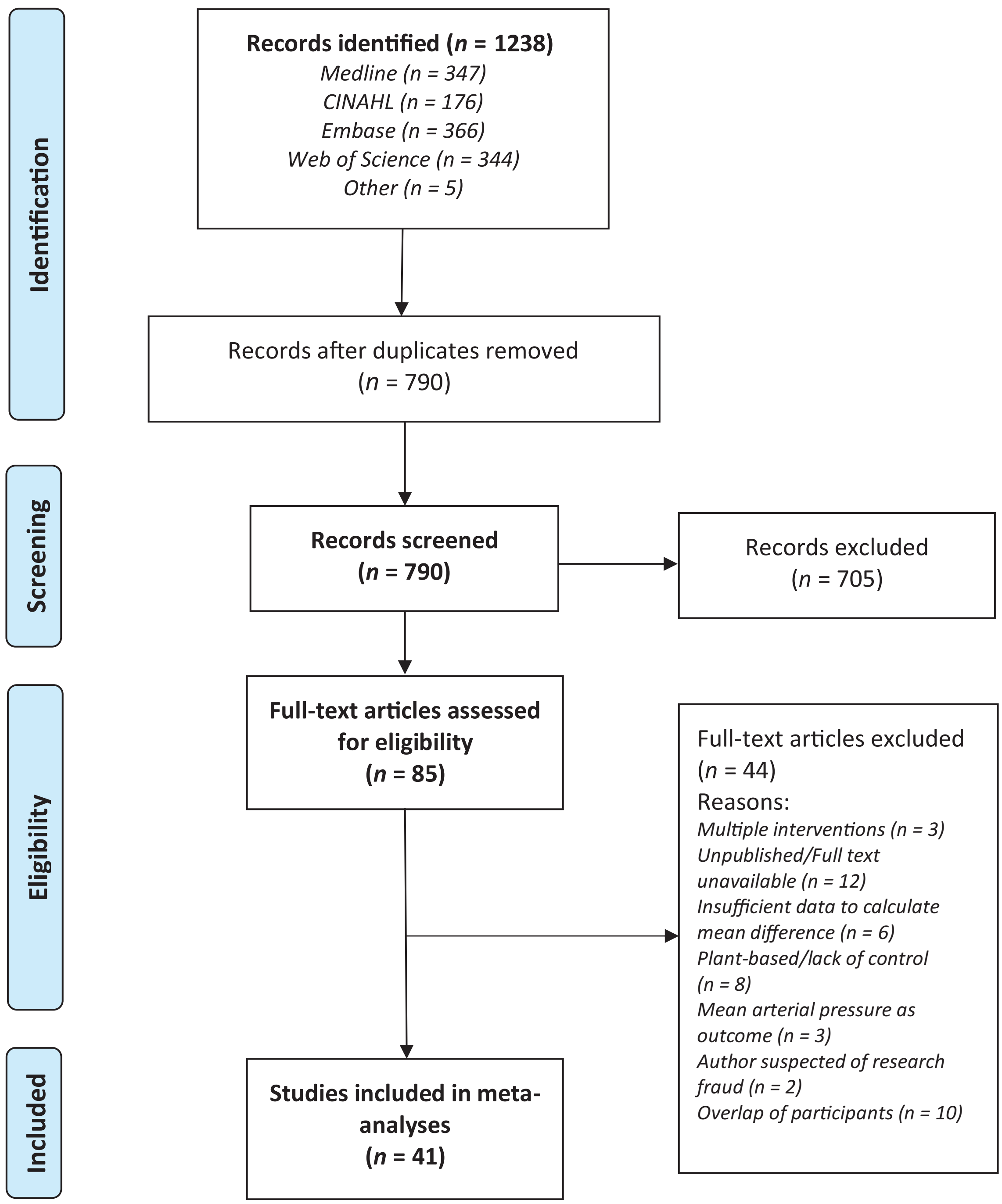

FIGURE 1 Preferred Reporting Items for Systematic reviews and Meta-analyses flow chart.

algebraically computed from the 95% confidence intervals (95% CIs) or SDs. The mean differences for individual studies were pooled, stratified by diet type, using a random-effects model. A subgroup analysis was then carried out, in which only studies with the participants usual/standard diet as the control were included.

Estimates of the overall net change in BP and 95% CIs associated with the consumption of each diet type were calculated, and each study was weighted by its inverse variance. The heterogeneity among studies was quantified by I^2-statistic. Funnel plots were developed to assess the impact of publication bias. Beggs's test and Egger's regression test were applied to measure funnel plot asymmetry. We conducted a one-study-removed analysis as a sensitivity analysis. This involved omitting one study at a time to assess the impact of each study on the combined effect. Subgroup analyses by mean age, duration of PBD consumption, antihypertensive medication use, baseline hypertensive status, and country/region were performed. Random effects meta-regression was used to determine if age, intervention duration, baseline BMI, or sex were significantly associated with heterogeneity.

TABLE 1. Study designs and participant characteristics of clinical trials included in the meta-analysis

Plant-based diet	Principal components
Healthy Nordic diet	Higher content of plant foods, fish, egg, and vegetable fat, and lower content of meat products, dairy products, sweets, desserts, and alcoholic beverages
High-fruit and vegetable diet	Increased consumption of fruit and vegetables. To further increase the polyphenolic load, some studies included regular dark chocolate content
High-fiber diet	Fiber is found in varying levels in all plant foods and is most prevalent in whole grains and legumes. For this reason, most high-fiber diets focus on increasing wholegrain and legume consumption
Lacto-ovo vegetarian diet	Defined as those that exclude the consumption of all meat, poultry, and fish but still include the consumption of dairy and eggs. The main components include fruit, vegetables, whole grains, legumes, and nuts and seeds
DASH diet	Encourages the consumption of fruits, vegetables, whole grains, nuts and seeds, and low-fat dairy products and limits the intake of sweets, saturated fat, and sodium
Mediterranean diet	The main components are daily consumption of vegetables, fruit, whole grains, olive oil, weekly consumption of legumes, nuts, fish, dairy, and eggs, and limited intake of meat
Vegan diet	Consists of plant foods exclusively. No animal flesh or other animal-derived products (including dairy and eggs) are included. It is mostly low-fat and focuses on the consumption of whole plant foods like fruits, vegetables, whole grains, legumes, and nuts and seeds

DASH, Dietary Approach to Stop Hypertension.

RESULTS

Study selection process

The search strategy retrieved 1238 articles. After removing duplicates, the title and abstract screening process identified 85 studies. Full-text assessment led to the exclusion of 44 articles from the systematic review (Supplementary Table S2, http://links.lww.com/HJH/B430). The remaining 41 articles met the inclusion criteria and had suitable data for meta-analyses (Fig. 1). Two additional publications were found through reference lists and hand searching.

Study characteristics

The 41 included studies were published between 1983 and 2019 [16–56] (Table 2 and Supplementary Table S3, http://links.lww.com/HJH/B430). The total sample size was 8416 (4429 in the intervention groups and 3987 in the control groups; median sample size 65; range 11–4717) and the mean age of the participants was 49.2 years (range 25.6–71.0 years). All included studies were controlled trials with a duration range of 1.4–208 weeks (median duration 12 weeks). Of the 41 clinical trials, two were not randomized [21,32]. Of the 39 RCTs, 26 reported the method of random generation and 13 failed to describe it (Supplementary Table S3, http://links.lww.com/HJH/B430). In addition, seven studies used a crossover design and 33 used a parallel design, of which two of the studies were single-blinded (Table 2) [26,47]. Two of the studies had controlled feeding [23,33] and all of the studies were free living. As shown in Table 2, 12 studies included participants who were taking antihypertensive medications. Foods were provided to the participants in 20 of the clinical trials. The interventions under investigation in the 41 studies are the DASH diet ($n = 11$), vegan diet ($n = 9$), Mediterranean diet ($n = 8$), lacto-ovo vegetarian diet ($n = 5$), healthy Nordic diet ($n = 3$), high-fiber diet ($n = 3$), and high-fruit and vegetables diet ($n = 2$) (Table 1). Thirty-two of the clinical trials reported how many BP measurements were taken, of these 31 reported repeated BP measurements. Nineteen of the studies adjusted for potential confounders (Supplementary Table S3, http://links.lww.com/HJH/B430). Thirty-two of the studies reported on the adherence of participants to the dietary interventions (Supplementary Table S3, http://links.lww.com/HJH/B430). Of these studies, 26 reported high adherence, four reported fair adherence [32,38,39,44], and two reported poor adherence [37,48]. Sixty percent of included studies indicate a low risk of bias for random sequence generation and allocation concealment. One hundred percent of the studies indicate a high risk of performance bias due to the nature of dietary interventions. Forty percent of the studies indicate a high risk of detection bias due to the lack of outcome assessor blinding. Ninety percent of the studies indicate a low risk of attrition bias and 42.5% of the studies indicate low risk of reporting bias. Finally, 10% of the studies indicate high risk for funding bias (Figs. 2 and 3, risk of bias).

Pooled effects of plant-based diets on blood pressure

Healthy Nordic diet

Compared with reference diets, the healthy Nordic diet involves higher intake of plant foods, fish, egg, and vegetable fat, and lower intake of meat products, dairy products, sweets, desserts, and alcoholic beverages [57]. In the three identified RCTs, consumption of the healthy Nordic diet was associated with a mean reduction in SBP (−4.47 mmHg; 95% CI, −7.14 to −1.81; $P = 0.001$; $I^2 = 31\%$; $P = 0.23$ for heterogeneity) (Fig. 2) and DBP (−2.32 mmHg; 95% CI, −3.83 to −0.82; $P = 0.002$; $I^2 = 0\%$; $P = 0.39$ for heterogeneity) (Fig. 3) compared with the consumption of comparator diets. In the one-study-removed analysis, results were mostly unaffected, with BP differences between the healthy Nordic and control groups ranging from −3.75 to −5.64 mmHg for SBP and −1.75 to −3.30 mmHg for DBP (Supplementary Table S4, http://links.lww.com/HJH/B430). The certainty of this evidence is moderate (Table 3).

High-fruit and vegetable diet

The high-fruit and vegetable diet is characterized by increased consumption of fruit and vegetables. To further increase the polyphenolic load, one of the studies included regular dark chocolate intake [47]. In the two clinical trials, consumption of the high-fruit and vegetables diet was associated with a mean reduction in SBP (−0.57 mmHg; 95% CI, −7.45 to −6.32; $P = 0.87$; $I^2 = 65\%$; $P = 0.09$ for heterogeneity) (Fig. 2) and DBP (−0.96 mmHg; 95% CI, −3.08 to −1.15; $P = 0.37$; $I^2 = 0\%$; $P = 0.43$ for heterogeneity) (Fig. 3) compared with the consumption of comparator

TABLE 2. Study designs and participant characteristics of clinical trials included in the meta-analysis

Author	Country	Year	Design	Duration (weeks)	No.	Age (years)	Men (%)	SBP (mmHg)	DBP (mmHg)	Rx (%)	BMI (kg/m^2)	Alcohol intake	Intervention	Reference diet	Food preparation
Rouse [16]	AUS	1983	RCT, O, C	6	38	40.1	50.0	127.7	76.4	0	23.7	Participants asked to not alter alcohol consumption	Lacto-ovo vegetarian	Habitual diet	Yes (2/d)
Margetts [17]	AUS	1985	RCT, O, P	12	39	49.9	71.8	155.4	99.9	0	27.6	Participants asked to not alter alcohol consumption	Lacto-ovo vegetarian	Habitual diet	Yes (meat substitutes)
Fehily [18]	UK	1986	RCT, O, C	8	201	36.0	73.1	132.1	79.8	1.5	NR	HF/LF, 11.5/13.6 g/day	High fiber	Low fiber	No
Kestin [19]	AUS	1989	RCT, O, C	6	17	44.0	100.0	128.0	79.0	0	25.5	Veg/Cont, 4.2/4.8% energy	Lacto-ovo vegetarian	Average Australian diet	Yes (major sources of protein and fat)
Hakala [20]	Finland	1989	RCT, O, P	52	73	38.0	24.7	129.9	85.0	0	34.4	2% of energy intake for Int. and Ctrl	Lacto vegetarian	Habitual diet	No
Little [21]	UK	1990	CT, O, P	8	81	57.6	49.4	139.9	78.0	NR	NR	4.9 unit/week	DASH	Habitual diet	No
Sciarrone [22]	AUS	1993	RCT, O, P	6	20	41.0	100.0	134.2	77.2	0	25.3	Individuals using >20 g of ethanol/d excluded	Lacto-ovo vegetarian	Average Australian diet	Yes
Appel [23]	USA	1997	RCT, O, P	11	305	44.3	50.4	131.8	85.1	94.8	28.1	Participants excluded if they consumed >14 drinks/week	DASH	Standard Western diet	Yes
Nicholson [24]	USA	1999	RCT, O, P	12	11	54.3	45.5	141.3	84.7	81.8	NR	Individuals using alcohol regularly were excluded	Vegan diet	Low-fat	All lunches and dinners
Broekmans [25]	NL	2001	RCT, O, P	4	47	49.3	51.1	127.5	80.5	NR	25.8	NR	High F&V	Low F&V	Yes
Esposito [26]	Italy	2004	RCT, SB, P	104	180	43.9	61.1	135.0	85.5	NR	28.0	Participants with active alcohol abuse excluded	MED	Prudent	No
Azadbakht [27]	Iran	2005	RCT, O, P	24	76	41.4	29.0	143.6	85.7	0	29.9	NR	DASH	Weight reducing diet	No
Nowson [28]	AUS	2005	RCT, O, P	12	54	48.0	100.0	135.0	88.4	33.3	30.4	DASH/LF, 12 /17.6 g/day	DASH	Low-fat	Dairy product of choice was provided once
Barnard [29]	USA	2009	RCT, O, P	74	98	55.6	39.4	123.3	78.0	69.7	34.9	Participants with active alcohol abuse excluded	Vegan diet	ADA diet	No
Nowson [30]	AUS	2008	RCT, O, P	14	95	59.2	0.0	127.6	81.0	36.8	29.6	Participants were excluded if they consumed >30 standard drinks/week	DASH + lean beef	Conventional advice	Some foods
Rallidis [31]	Greece	2009	RCT, O, P	8	82	50.4	52.4	129.9	86.1	NR	32.2	Participants were excluded if they consumed >500 g/week	MED	Conventional advice	Some foods
Ferdowsian [32]	USA	2010	CT, O, P	22	113	44.4	17.7	117.8	79.7	NR	NR	Participants with active alcohol abuse excluded	Vegan diet	Habitual diet	Yes (2/d)
Blumethal [33]	USA	2010	RCT, O, P	16	94	51.8	33.7	137.8	85.8	0	32.9	NR	DASH	Habitual diet	No
Adamsson [34]	Sweden	2011	RCT, O, P	6	86	53.0	59.3	128.8	82.1	NR	26.4	Nord/Cont, 1.7/2.1% energy	Healthy Nordic	Habitual diet	Yes
Azadbakht [35]	Iran	2011	RCT, O, C	8	31	NR	58.0	136.0	81.9	NR	NR	NR	DASH	Average Iranian diet	No
Morenga [36]	NZ	2011	RCT, O, P	8	74	41.9	0.0	125.0	80.0	NR	34.0	5.48 g/day	High fiber	High protein	No
Brooking [37]	NZ	2012	RCT, O, P	24	41	41.4	30.4	126.3	79.7	8.9	34.8	NR	High fiber	Habitual diet	Yes (food basket at start)
Toledo [38]	Spain	2013	RCT, O, P	208	4717	66.9	43.2	149.0	82.5	70.3	29.9	Participants with active alcohol abuse excluded	MED + nuts	Low-fat	Yes (30 g of nuts/d)
Mishra [39]	USA	2013	RCT, O, P	18	215	45.2	17.2	127.0	81.9	NR	33.8	Participants with active alcohol abuse excluded	Vegan diet	Habitual diet	No
Uusitupa [40]	Nordic countries	2013	RCT, O, P	18	189	54.4	33.3	130.0	82.0	51.9	31.6	Participants were excluded if they consumed >40 g/day	Healthy Nordic	Standard Nordic diet	Yes (key food groups every 1–2 weeks)
Poulsen [41]	Denmark	2014	RCT, O, P	26	145	42.1	29.3	122.5	81.3	NR	30.3	NND/ADD, 0.02%/0.00% energy	Healthy Nordic	Average Danish diet	Yes

TABLE 2 (*Continued*)

Author	Country	Year	Design	Duration (weeks)	No.	Age (years)	Men (%)	SBP (mmHg)	DBP (mmHg)	Rx (%)	BMI (kg/m^2)	Alcohol intake	Intervention	Reference diet	Food preparation
Macknin [42]	USA	2015	RCT, O, P	4	28	46.3	32.1	123.4	78.8	NR	35.2	NR	Vegan diet	AHA	No
Lee [43]	AUS	2015	RCT, O, C	1.4	24	25.6	0.0	113.2	75.3	NR	23.0	Participants with active alcohol abuse excluded	MED	Habitual diet	No
Wong [44]	China	2015	RCT, O, P	52	405	55.1	49.0	145.0	90.2	0	24.2	87.1% nondrinkers, 12.9% current/ex-drinkers	DASH	Conventional	No
Bunner [45]	USA	2015	RCT, O, P	20	34	57.0	44.1	141.9	84.4	NR	36.0	Consumption is more than two drinks per day	Vegan diet	Habitual diet	No
Lee [46]	S Korea	2016	RCT, O, P	12	93	57.9	19.4	126.6	76.9	43.0	23.5	NR	Vegan diet	Korean Diabetes Association	No
Noad [47]	UK	2016	RCT, SB, P	8	93	54.8	53.8	141.2	85.0	78.5	30.7	Men excluded if consumed >28 unit/week and women if >21 unit/week	High F&V	Low F&V	F&V
Davis [48]	AUS	2017	RCT, O, P	24	136	71.0	43.6	124.2	71.0	NR	26.9	NR	Med diet	Habitual diet	Some foods
Wright [49]	NZ	2017	RCT, O, P	12	65	56.0	40.0	132.5	79.5	NR	34.4	Participants with active alcohol abuse excluded	Vegan diet	Conventional	No
Barnard [50]	USA	2018	RCT, O, P	20	22	61.0	46.7	129.5	77.9	NR	33.9	Excluded if alcohol consumption >2 drinks/day	Vegan diet	Portion-controlled diet	No
Kucharska [51]	Poland	2018	RCT, O, P	12	126	59.8	50.8	130.5	84.2	100.0	32.8	<2 drinks/d = 31%, >2 drinks/d = 4%	DASH	Conventional	No
Lee [52]	Korea	2018	RCT, O, P	8	58	43.2	70.7	134.9	86.4	NR	25.2	Participants were excluded if they consumed >14 servings/week	DASH	Conventional	No
Wade [53]	AUS	2018	RCT, O, C	24	41	60.2	31.7	129.5	87.8	0	30.8	MD/LF, 4.58/5.65% energy	MED + dairy	Low-fat	Some foods
Hashemi [54]	Iran	2019	RCT, O, P	12	75	NR	38.7	130.0	87.3	NR	NR	Participants excluded if they consumed alcohol	DASH	ADA diet	No
Wade [55]	AUS	2019	RCT, O, C	8	31	61.0	30.3	128.9	76.1	0	30.6	MD/LF, 4.41/3.54% energy	MED + lean pork	Low-fat	Some foods
Mayr [56]	AUS	2019	RCT, O, P	24	65	61.8	83.1	136.8	82.1	NR	29.9	NR	MED	Low-fat	No

ADA, American Diabetic Association; AHA, American Heart Association; BMI, (weight in kilograms divided by height in meters squared); BP, blood pressure; C, crossover; Cont, control; CT, controlled trial; DASH, Dietary Approach to Stop Hypertension; F&V, fruit and vegetables; HF, high fiber; LF, low-fat; MD, moderate; MED, Mediterranean; NR, not reported; O, open label; P, parallel; RCT, randomized controlled trial; SB, single-blind; Veg, vegetarian.

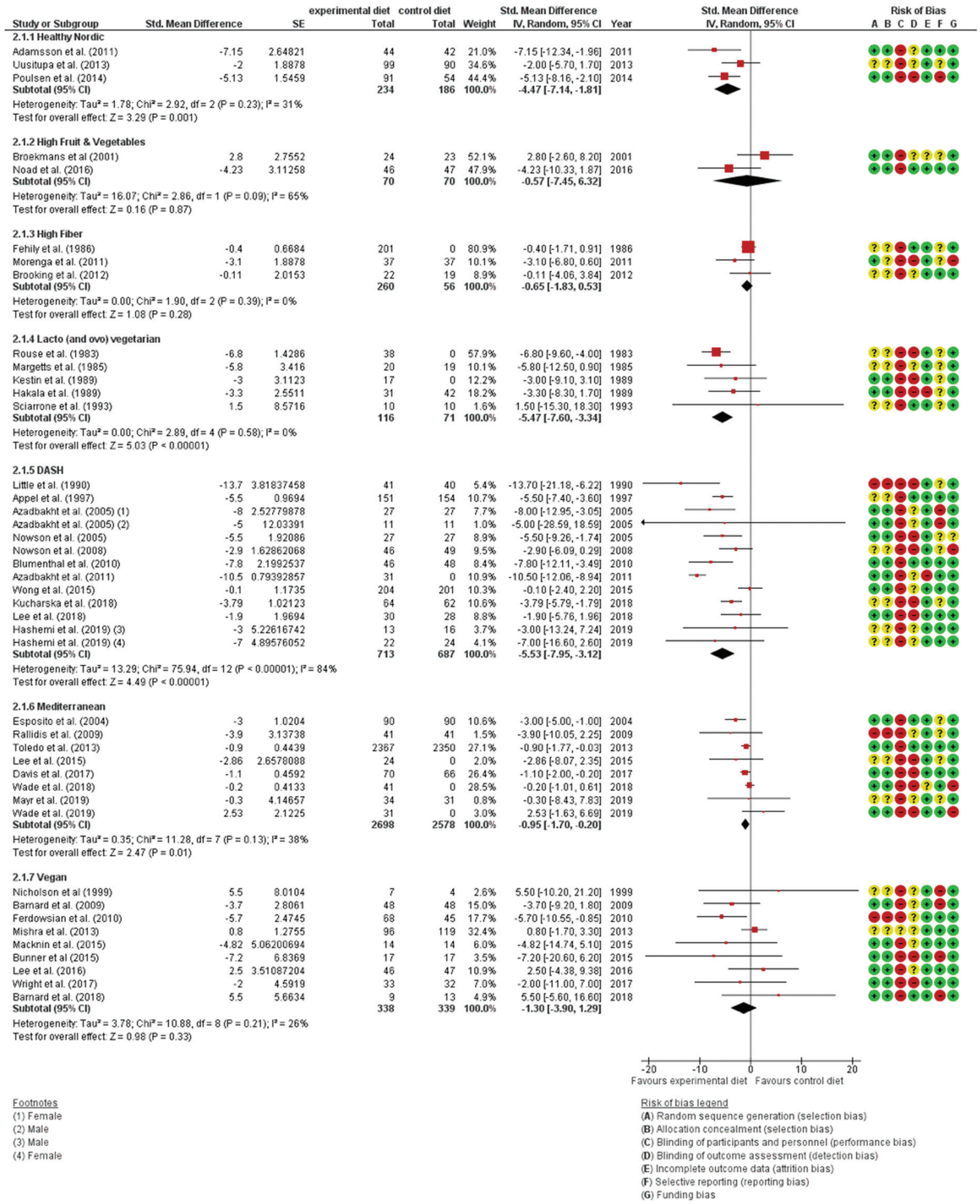

FIGURE 2 The effects of various plant-based diets on SBP. Results are expressed as mean difference (95% confidence interval).

diets. This subgroup was not suitable for a one-study-removed analysis as it only comprised two studies. Overall, the certainty of this evidence is very low (Table 3).

High-fiber diet

Fiber is found in varying levels in all plant foods and is most prevalent in whole grains and legumes. For this reason, most high-fiber diets focus on increasing wholegrain and legume consumption [36]. In the three controlled trials, consumption of the high-fiber diet was associated with a mean reduction in SBP (−0.65 mmHg; 95% CI, −1.83 to −0.53; $P = 0.28$; $I^2 = 0\%$; $P = 0.39$ for heterogeneity) (Fig. 2) and DBP (−1.02 mmHg; 95% CI, −3.86 to −1.82; $P = 0.0.48$; $I^2 = 75\%$; $P = 0.02$ for heterogeneity) (Fig. 3) compared with

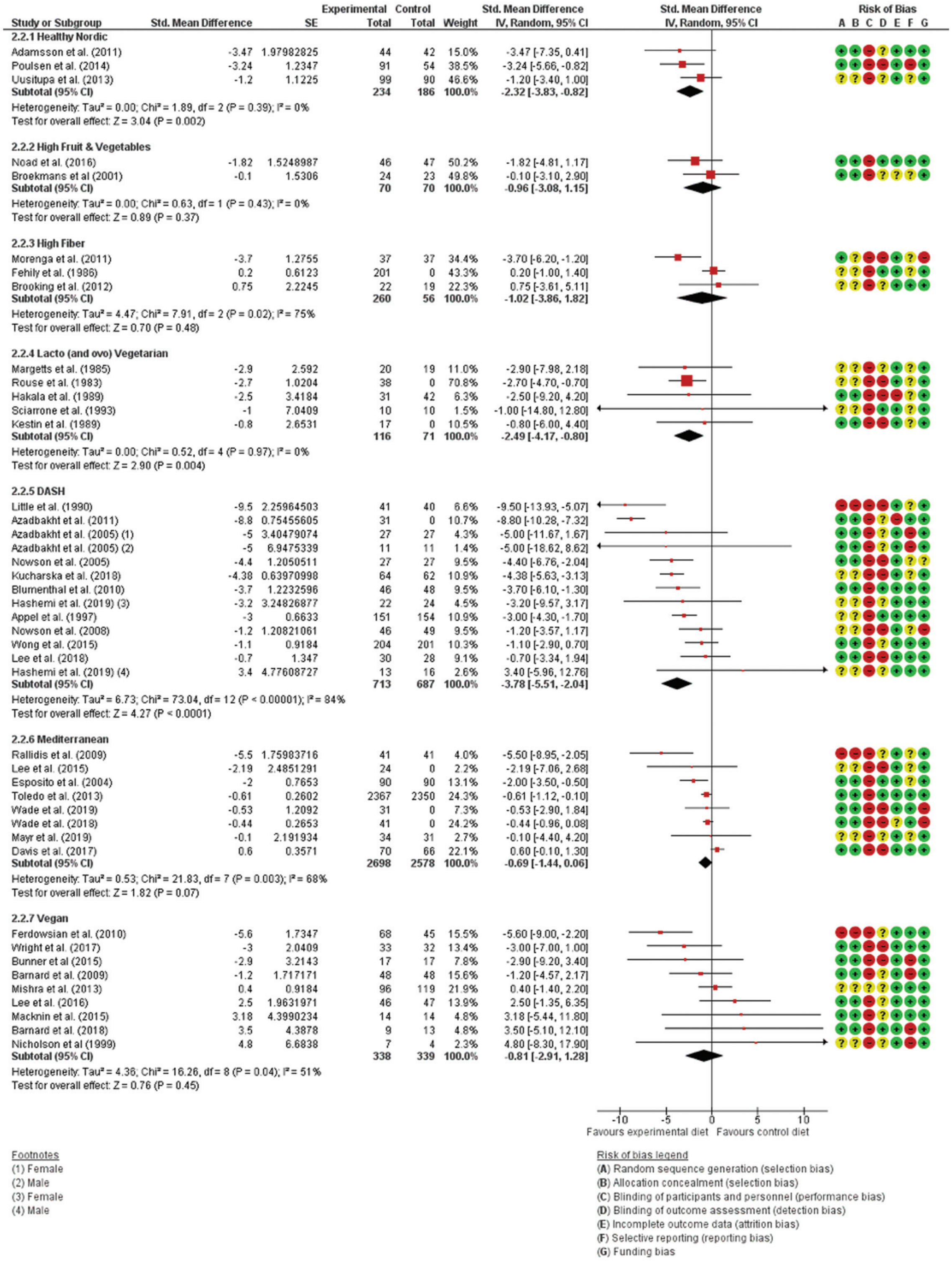

FIGURE 3 The effects of various plant-based diets on DBP. Results are expressed as mean difference (95% confidence interval).

the consumption of comparator diets. The one-study-removed analysis identified the study of Te Morenga *et al.* [36] as a source of heterogeneity. Removal of this study reduced the DBP effect heterogeneity from 75 to 0% (Supplementary Table S4, http://links.lww.com/HJH/B430). The mean differences produced by this removal were −0.37 (−1.61 to 0.87) and 0.24 (−0.92 to 1.40) mmHg for SBP and DBP, respectively (Supplementary Table S5, http://links.lww.com/HJH/B430). The certainty of this evidence is very low (Table 3).

Lacto-ovo vegetarian diet

Lacto-ovo vegetarian dietary patterns are defined as those that exclude the consumption of all meat, poultry, and fish

TABLE 3. GRADE summary of findings

Outcomes	Effect (95% CI)	No of participants (no of studies)	Certainty of the evidence (GRADE)	Comments
Change in SBP (mmHg) – healthy Nordic	SMD 4.47 lower (7.14 lower to 1.81 lower)	420 (3)	⊕⊕⊕○ Moderate[a,b,c,d]	
Change in SBP (mmHg) – High-fruit and vegetables	SMD 0.57 lower (7.45 lower to 6.32 higher)	140 (2)	⊕○○○ Very low[a,e,f]	
Change in SBP (mmHg) – High fiber	SMD 0.65 lower (1.83 lower to 0.53 higher)	316 (3)	⊕○○○ Very low[a,b,c,g]	
Change in SBP (mmHg) – Lacto (and ovo) vegetarian	SMD 5.47 lower (7.6 lower to 3.34 lower)	187 (5)	⊕⊕⊕⊕ High[a,b,c,h]	
Change in SBP (mmHg) – DASH	SMD 5.53 lower (7.95 lower to 3.12 lower)	1400 (11)	⊕⊕⊕⊕ High[a,b]	One study was not randomized
Change in SBP (mmHg) – Mediterranean	SMD 0.95 lower (1.7 lower to 0.2 lower)	5276 (8)	⊕⊕⊕○ Moderate[a,b,i]	
Change in SBP (mmHg) – Vegan	SMD 1.30 lower (3.90 lower to 1.29 higher)	677 (9)	⊕⊕○○ Low[a,d,j]	One study was not randomized
Change in DBP (mmHg) – healthy Nordic	SMD 2.32 lower (3.83 lower to 0.82 lower)	420 (3)	⊕⊕⊕○ Moderate[a,b,c,d]	
Change in DBP (mmHg) – high-fruit and vegetables	SMD 0.96 lower (3.08 lower to 1.15 higher)	140 (2)	⊕○○○ Very low[a,e,f]	
Change in DBP (mmHg) – high fiber	SMD 1.02 lower (3.86 lower to 1.82 higher)	316 (3)	⊕○○○ Very low[a,b,c,g]	
Change in DBP (mmHg) – Lacto (and ovo) vegetarian	SMD 2.49 lower (4.17 lower to 0.8 lower)	187 (5)	⊕⊕⊕○ Moderate[a,b,c,h]	
Change in DBP (mmHg) – DASH	SMD 3.78 lower (5.51 lower to 2.04 lower)	1400 (11)	⊕⊕⊕⊕ High[a,b]	One study was not randomized
Change in DBP (mmHg) – Mediterranean	SMD 0.69 lower (1.44 lower to 0.06 higher)	5276 (8)	⊕⊕⊕○ Moderate[a,b,i]	
Change in DBP (mmHg) – vegan	SMD 0.81 lower (2.91 lower to 1.28 higher)	677 (9)	⊕⊕○○ Low[a,d,j]	One study was not randomized

BP, blood pressure; CI, confidence interval; DASH, Dietary Approach to Stop Hypertension; SMD, standardized mean difference.
[a]Participants were not blinded in all studies.
[b]Experimental personnel were not blinded in some studies.
[c]Outcome assessor was not blinded in some studies.
[d]Selective reporting. The preregistered protocol did not list BP as an outcome for some studies.
[e]Only two studies, each showing opposite results.
[f]Small sample size led to large 95% CIs.
[g]Morenga *et al.* found a significantly larger effect compared with the other studies.
[h]Large no. of dropouts and no intention-to-treat analysis for some studies.
[i]Two of the studies were industry funded.
[j]Wide 95% CI that overlaps with no effect.

but still include the consumption of dairy and eggs [20]. The main components of the lacto-ovo vegetarian diets included in this study are fruit, vegetables, whole grains, legumes, and nuts and seeds. In the five clinical trials, consumption of the lacto-ovo vegetarian diet was associated with a mean reduction in SBP (−5.47 mmHg; 95% CI, −7.60 to −3.34; $P < 0.00001$; $I^2 = 0\%$; $P = 0.58$ for heterogeneity) (Fig. 2) and DBP (−2.49 mmHg; 95% CI, −4.17 to −0.80; $P = 0.004$; $I^2 = 0\%$; $P = 0.97$ for heterogeneity) (Fig. 3) compared with the consumption of comparator diets. There was no overall heterogeneity for the lacto-ovo vegetarian results. The certainty of the SBP result is high; however, the certainty of the DBP result is moderate (Table 3). It is to note that about 50% of the contribution to the overall estimate was weighted in favor of a single study [16].

Dietary Approach to Stop Hypertension diet

The DASH diet encourages the consumption of fruits, vegetables, whole grains, nuts and seeds, and low-fat dairy products and limits the intake of sweets, saturated fat, and sodium [58,59]. In the 11 identified clinical trials, consumption of the DASH diet was associated with a mean reduction in SBP (−5.53 mmHg; 95% CI, −7.95 to −3.12; $P < 0.00001$; $I^2 = 84\%$; $P < 0.00001$ for heterogeneity) (Fig. 2) and DBP (−3.78 mmHg; 95% CI, −5.51 to −2.04; $P < 0.0001$; $I^2 = 84\%$; $P < 0.00001$ for heterogeneity) (Fig. 3) compared with the consumption of comparator diets. Removal of three studies [21,35,44] reduced the SBP effect heterogeneity from 84 to 0% and changed the mean reduction in SBP to −4.70 (−5.76 to −3.63) mmHg (Supplementary Table S5, http://links.lww.com/HJH/B430). Removal of five studies [21,30,35,44,52] also reduced the DBP effect heterogeneity from 84 to 0% and changed the mean reduction in DBP to −3.75 (−4.53 to −2.97) mmHg (Supplementary Table S5, http://links.lww.com/HJH/B430). The certainty of this evidence is high (Table 3). Finally, the DASH diet was implemented with either a fixed moderate sodium consumption [23,33,35,54] or with tips given to participants to reduce sodium consumption [21,27,44,52]. We carried out a sensitivity analysis between the two groups of trials and did not detect a significant difference in the estimates of effects on BP [for SBP −6.45 (−9.34 to −3.55) vs. −4.25 (−9.44 to −0.95) mmHg, P for interaction = 0.47; for DBP −3.95 (−6.64 to −1.26) vs. −3.63 (−6.92 to −0.33) mmHg, P for interaction = 0.88, respectively]. These results do not detect the well known additive BP-lowering effect of sodium reduction to the core DASH diet [60]. This could be due to the fact that simple tips to reduce sodium intake may not have led to a true reduction in consumption, evidence not available in the individual trials as sodium excretion was not measured.

Mediterranean diet

The main components of the Mediterranean diet are daily consumption of vegetables, fruit, whole grains, olive oil, weekly consumption of legumes, nuts, fish, dairy, and eggs, and limited intake of meat [48]. In the eight clinical trials, consumption of the Mediterranean diet was associated with a mean reduction in SBP (−0.95 mmHg; 95% CI, −1.70 to

−0.20; $P=0.01$; $I^2=38\%$; $P=0.13$ for heterogeneity) (Fig. 2) and DBP (−0.69 mmHg; 95% CI, −1.44 to −0.06; $P=0.07$; $I^2=68\%$; $P=0.003$ for heterogeneity) (Fig. 3) compared with the consumption of comparator diets. Removal of two studies [26,55] reduced the SBP effect heterogeneity from 38 to 0% and changed the mean reduction in SBP to −0.97 (−1.58 to −0.36) mmHg (Supplementary Table S5, http://links.lww.com/HJH/B430). Removal of two different studies [31,48] reduced the DBP effect heterogeneity from 68 to 0% and changed the mean reduction in DBP to −0.61 (−0.96 to −0.26) mmHg (Supplementary Table S5, http://links.lww.com/HJH/B430). The certainty of this evidence is moderate (Table 3).

Vegan diet

Vegan diets consist of plant foods exclusively. No animal flesh or other animal-derived products (including dairy and eggs) are included in the diet. The vegan diets included in this study are mostly low-fat and focus on the consumption of whole plant foods like fruits, vegetables, whole grains, legumes, and nuts and seeds [50]. In the nine controlled trials, consumption of the vegan diet was associated with a mean reduction in SBP (−1.30 mmHg; 95% CI, −3.90 to −1.29; $P=0.33$; $I^2=26\%$; $P=0.21$ for heterogeneity) (Fig. 2) and DBP (−0.81 mmHg; 95% CI, −2.91 to −1.28; $P=0.45$; $I^2=51\%$; $P=0.04$ for heterogeneity) (Fig. 3) compared with the consumption of comparator diets. In the one-study-removed analysis, SBP results had some diversity, with SBP differences between the vegan and control groups ranging from 0.05 to −2.49 mmHg (Supplementary Table S4, http://links.lww.com/HJH/B430). Removal of one study [32] reduced the SBP effect heterogeneity from 26 to 0% and changed the mean reduction in SBP to 0.05 (−1.94 to 2.03) mmHg (Supplementary Table S5, http://links.lww.com/HJH/B430). Removal of the same study reduced the DBP effect heterogeneity from 51 to 0% and changed the mean reduction in DBP to 0.08 (−1.23 to 1.38) mmHg (Supplementary Table S5, http://links.lww.com/HJH/B430). The certainty of this evidence is low (Table 3).

Meta-regression

The meta-regression identified age as a potential source of heterogeneity in the DBP mean differences obtained from the clinical trials investigating the Mediterranean diet (β coefficient, 0.081; $P=0.049$) (Supplementary Table S6, http://links.lww.com/HJH/B430). Intervention duration, baseline BMI, and sex (proportion of men) were not statistically significant sources of heterogeneity for any of the dietary interventions (Supplementary Table S6, http://links.lww.com/HJH/B430). These results suggest that the mean reduction in DBP associated with the consumption of the Mediterranean diet is less pronounced among older individuals.

Publication bias

The Egger's and Begg's statistical tests found no significant funnel plot asymmetry for any of the dietary interventions (Supplementary Table S7, http://links.lww.com/HJH/B430).

Standardized control diet analysis

We carried out a secondary analysis including only trials that employed the habitual diet of the participants or average diet of the specific population as the control diet, in an attempt to standardize control groups (Table 4). Compared with the consumption of the standardized control diet, consumption of PBDs was associated with a mean reduction in SBP (−4.29 mmHg; 95% CI, −6.27 to −2.31; $P \leq 0.0001$; $I^2=87\%$; $P \leq 0.00001$ for heterogeneity) and DBP (−2.79 mmHg; 95% CI, −4.33 to −1.24; $P=0.0004$; $I^2=88\%$; $P \leq 0.00001$ for heterogeneity).

DISCUSSION

The results of our study show, with varying certainty, that plant-based dietary patterns reduce SBP and DBP.

The Healthy Nordic and Mediterranean diets produce statistically significant reductions in SBP. The certainty of this evidence is moderate. This finding is of great significance as it shows that complete eradication of animal products from one's diet is not necessary to produce significant improvements in BP. Therefore, these diets can be considered as achievable lifestyle modifications for those trying to lower their BP.

Our results show with high certainty that both the lacto-ovo vegetarian and DASH diets significantly reduce BP. This confirms the results of a previous meta-analysis of clinical trials and observational studies that found vegetarian dietary patterns are effective at reducing BP [11]. Our results are also in accord with another meta-analysis which found that the DASH, Mediterranean, and Nordic diets are effective at lowering BP [61]. These results reinforce the

TABLE 4. The effects of various plant-based diets on SBP and DBP when compared with a standardized control diet

Diet	Studies, n	Sample size: Intervention	Sample size: Control	SBP difference (mmHg)	95% CI	DBP difference (mmHg)	95% CI
Healthy Nordic diet	3	234	186	−4.47	−7.14, −1.81	−2.32	−3.83, −0.82
High-fruit and vegetables	2	70	70	−0.57	−7.45, 6.32	−0.96	−3.08, 1.15
High fiber	2	59	56	−1.69	−4.61, 1.24	−1.85	−6.15, 2.45
Lacto (and ovo) vegetarian	5	116	71	−5.47	−7.60, −3.34	−2.49	−4.17, −0.80
DASH	4	269	242	−8.74	−12.20, −5.28	−6.05	−9.60, −2.50
Mediterranean	2	94	66	−1.15	−2.04, −0.26	0.29	−1.43, 2.01
Vegan	3	181	181	−2.73	−8.29, 2.83	−2.48	−6.91, 1.94
Pooled	**21**	**1023**	**872**	**−4.29**	**−6.27, −2.31**	**−2.79**	**−4.33, −1.24**

Results are expressed as mean difference (95% confidence intervals). CI, confidence interval; DASH, Dietary Approach to Stop Hypertension.

concept that complete eradication of animal products is not necessary for BP reduction, and also add that dietary salt reduction is a powerful tool in adjunct with increased plant-food consumption.

The vegan diet did not significantly reduce BP; however, the certainty of this result is low. This result is in line with a recent meta-analysis suggesting that the changes in BP induced by a vegan diet without caloric restrictions are comparable with those induced by other dietary approaches recommended by medical societies [12]. On the other hand, it is likely that the effectiveness of vegan diets at lowering BP has been underestimated by the use BP-lowering comparator diets. When only including the vegan studies with the participants usual diet as the comparator, the overall effect estimate becomes statistically significant, but the certainty remains low.

The results for the high-fruit and vegetables and high-fiber diets had a very low certainty, largely due to the small number of studies identified for these interventions. Due to this limitation, it is difficult to determine whether simply increasing fruit and vegetable or whole-grain consumption is sufficient to produce a significant reduction in BP. Since these diets may be the most achievable for the general population to adhere, it is imperative that further controlled trials are conducted to confidently establish the effect of consumption on BP.

Our study shows that the healthy Nordic, ovo-lacto vegetarian, and DASH diets are more effective at reducing BP than the Mediterranean diet, since the 95% CIs of all three diets do not overlap with the 95% CI of the Mediterranean diet effect estimate.

Consistent with our findings, an analysis of three prospective cohorts (Nurses' Health Study I, Nurses' Health Study II, and Health Professionals Follow-up Study) totaling 188 518 participants, found a positive association between animal flesh consumption and hypertension risk, independent of fruit, vegetable, and whole-grain consumption [9]. Similarly, compared with vegetarians, fish eaters, and meat eaters, vegans had the lowest prevalence of hypertension in a cross-sectional analysis of the European Prospective Investigation into Cancer and Nutrition-Oxford study (11 004 participants) [62]. In a calibration substudy of the Adventist Health Study-2, the BP of habitual vegans, lacto-ovo vegetarians, and nonvegetarians was compared for the first time in the literature [63]. The analysis found that vegans and lacto-ovo vegetarians had significantly lower SBP and DBP, as well as significantly lower odds of hypertension (63 and 43%, respectively) when compared with nonvegetarians. This is important since nonvegetarian Seventh Day Adventists often consume less meat than individuals consuming a typical western diet [64].

Strengths and limitations

The current review has six key strengths: first, it is the first review to have a comprehensive inclusion of all diets with a plant-based component; second, the standardized control diet analysis allowed us to broadly compare the effect of consuming PBDs versus the standard control diet on BP, and to specifically identify which plant-based subdiets are optimal for lowering BP; third, the included trials provided a moderately large sample size that promotes confidence in the results; fourth, 95% of the included trials were RCTs; fifth, there was a lack of detectable publication bias for the included studies; sixth, the studies responsible for heterogeneity were identified and the results were largely unaffected by their exclusion.

Some limitations of this review should be noted. First, there was a low number of clinical trials investigating the healthy Nordic diet, high-fiber diet, and high-fruit and vegetables diet. This issue was exacerbated when standardizing for the control diet. Second, this review carried forward the design limitations of the included clinical trials. Most prominent in this regard is small sample sizes. Third, some of the clinical trials were of poor quality mainly due to lack of blinding of study personnel. Due to the nature of dietary interventions, double blinding was not possible in any of the included clinical trials. Fourth, some of the clinical trials did not adjust the BP outcomes for confounding factors. Finally, the food and nutrient compositions of the diets used in each clinical trial varied, so the effect of individual nutrients could not be identified.

Potential mechanisms

The current review supports a causal relationship between the consumption of PBDs and subsequent reduction in SBP and DBP. There are numerous lines of evidence to suggest possible mechanisms. First, PBD eaters have improved endothelial function compared with omnivores [65], due to two possible mechanisms. Animal fat transports bacterial endotoxins into the bloodstream which elicits an inflammatory response [66]. This inflammation can impair endothelial function within a few hours of animal fat consumption, thus worsening the ability of blood vessels to dilate [67]. A lower fat content can then be contributing to improved endothelial function. Furthermore, flavonoid-rich fruits and nitrate-rich vegetables can increase plasma nitric oxide concentrations, which improves endothelial function and decreases BP within hours of consumption [68]. Second, due to the low energy density of whole plant foods, PBD eaters usually have lower BMIs and lower obesity risk compared with omnivores [69]. However, this is unlikely to be the only mechanism responsible for the BP reduction produced by PBDs as trials that maintain body weight still demonstrate a BP-lowering effect [14]. Third, PBDs are rich in potassium. Meta-analyses of RCTs investigating the effect of potassium supplementation on BP found that increased potassium intake reduces BP and risk of strokes [70]. High-potassium intake may achieve BP reduction through many mechanisms, including, vasodilation, increased glomerular filtration rate, and decreased renin, renal sodium reabsorption, reactive oxygen species production, and platelet aggregation [71]. Additional cerebrovascular benefits have also been described in animal experiments, such as increased luminal and outer diameter of cerebral arteries and reduced cerebral infarct size due to potassium supplementation [72]. Fourth, PBDs may have a lower sodium content compared with the standard western diet. It is estimated that three-quarters of an individual's sodium intake comes from processed foods [73], therefore, switching one's calorie source to whole plant foods may lead to decreased sodium intake. Alternative potential mechanisms include greater antioxidant and anti-inflammatory effects, improved insulin sensitivity, decreased blood viscosity, altered baroreceptors, modifications in both renin–angiotensin, and sympathetic nervous systems, modification of the gut microbiota [74].

Implications

Raised BP is the leading risk factor for mortality globally, accounting for about 12.8% of all deaths [4]. The decrease in BP caused by the consumption of PBDs can have important health benefits at the population level. According to McPherson *et al.* [75], a 5 mmHg reduction in SBP in the population of the United Kingdom would reduce the prevalence of hypertension by an estimated 50% in that country. A SBP reduction of this scale is also expected to result in a 7, 9, and 14% overall reduction in mortality due to all causes, coronary heart disease, and stroke, respectively [76].

The health benefits of PBDs stretch beyond improved BP. The EAT-Lancet Commission on healthy diets for sustainable food systems highlights the fact that unhealthy diets represent a greater risk of morbidity and mortality than does unsafe sex, and alcohol, drug, and tobacco use combined [77]. In an analysis of the PREDIMED study that assigned the diets of the participants with a provegetarian score, the highest scoring group of participants achieved a 41% reduction in mortality compared with the lowest scoring group [78]. Similarly, in an analysis of nearly 25 000 participants from the National Health and Nutrition Examination Survey, Mazidi *et al.* [79] found that participants with the lowest carbohydrate intake had the highest risk of overall (32%), cardiovascular disease (50%), cerebrovascular (51%), and cancer (36%) mortality. PBDs are associated with a lower risk of overweight and/or obesity (15%) [80], type 2 diabetes (23%) [81], cardiovascular disease (16%), cardiovascular disease mortality (31–32%), and all-cause mortality (18–25%) [82]. Other meta-analyses of clinical trials have found that PBDs significantly reduce glycosilated haemoglobin [83], LDL cholesterol [84], and body weight [85]. Therefore, PBDs are a useful tool for disease prevention, and they may also be clinically relevant in the treatment of some noncommunicable diseases, for example coronary artery disease [86], type 2 diabetes [87], and prostate cancer [88].

Plant-based dietary patterns also play an important role in global food sustainability and security [77]. According to the Intergovernmental Panel on Climate Change (IPCC), if we switched to a 100% plant-based food system in 2050, adequate food production could be achieved on less land than is currently used [89]. This is not surprising considering that more than half of the world's crops are used to feed animals, not people [90]. It is estimated that the livestock sector accounts for 80% of total anthropogenic land use [91]. The livestock sector is also a significant burden on the fresh water supply. Agriculture consumes about 70% of global fresh water [92]. Approximately 43 000 l of water is required to produce 1 kg of beef but in contrast, it only takes 1000 l to produce 1 kg of grain [92]. Therefore, PBDs may play a pivotal role in water conservation. The livestock sector has massive implications on global warming. It is accountable for approximately 18% of global greenhouse gas emission [90]. The IPCC reported that the vegan diet is the most powerful diet at mitigating greenhouse gas emission, and estimated that the adoption of a 100% plant-based food system in 2050 would save about 8 Gt CO_2-eq/year [88]. Recently, Eshel *et al.* [93] have estimated that Americans can eliminate land-use for pasture, whilst simultaneously saving 35–50% of their diet-related needs for cropland, reactive nitrogen, and greenhouse gas emission if all US meat is replaced with plant alternatives.

Barriers

While our study supports the concept that PBDs are efficacious in lowering BP, the success of a dietary intervention aiming at reducing BP in healthy populations or specific patient groups (effectiveness) depends on a variety of factors related to both individual behaviors and to policy approaches. Sociodemographic factors determine an individual's ability to adopt a PBD. A study using data from 1890 Finns found that the most important barrier to following a PBD is related to meat appreciation [94]. The preference for familiarity and the perceived nutritional necessity of meat contributes greatly to the barrier effect. The association of meat consumption with masculinity and the perceived difficulty of preparing plant-based meals also adds resistance to change. Other barriers preventing people from following a PBD are rural residence, low education, and young age. In another study conducted in the United Kingdom, fruit and vegetable expense was also found as a barrier to increased plant-food consumption [95]. To overcome these barriers, we ought to formulate strategies to influence beliefs about PBDs, plant food availability, and cost of plant foods.

PBDs are generally assumed to have lower adherence and acceptability rates than more typical omnivorous therapeutic diets. Evidence from controlled clinical trials, however, suggests a more complex issue. In a randomized trial of 63 overweight and obese patients allocated to a variety of PBDs compared with an omnivorous diet, there was no significant difference in dietary acceptability and/or adherence between the dietary patterns after 6 months when validated measures of dietary acceptability and adherence were applied [96]. Regardless of the low adherence rates amongst participants, nonadherent vegan and vegetarian participants experienced greater weight loss than nonadherent omnivorous participants. A systematic review found similar results in interventions lasting more than a year [97]. Adherence rates ranged from 51 to 61% for vegan and vegetarian diets and 20 to 55% for omnivorous diets. There was no difference in acceptability across diets. The same review also found that the consumption of vegan diets improved quality of life. Individuals prescribed these diets reported weight loss, increased energy, decreased menstrual pain, and improved digestion and sleep. These general improvements in well being likely influence the acceptability of PBDs. Finally, nutritional interventions in treated hypertensive patients, predominantly based on weight, sodium and alcohol reduction, have been effective in reducing the use of antihypertensive medications over a 4-year period [98]. Likewise, increasing potassium consumption with food led to the same result over a year in an Italian trial [99]. Finally, large natural population experiments in Finland (North Karelia) have demonstrated the feasibility of substantive dietary changes with sustained beneficial health effects over decades [100]. Longer term trials on PBDs are nevertheless warranted to explore the generalizability and applicability of this specific dietary approach.

In conclusion, a shift towards healthy diets globally requires focus on environmental sustainability of food production and health consequences of final consumption, requiring multisectoral actions, science and evidence-gathering and a full range of policy changes. A healthy reference diet has been suggested [77]. It would largely consist of an increase in plant-based foods with limited or no animal products. Our study provides new comprehensive evidence to support this pledge, indicating that such diets would significantly lower both SBP and DBP, across sex and BMI, with likely health benefits on a global scale.

Journal of Hypertension 2020_compressed Video, http://links.lww.com/HJH/B431.

ACKNOWLEDGEMENTS

The present analysis was carried out under the terms of reference of the WHO Collaborating Centre for Nutrition (UNK-257) at the University of Warwick. The authors alone are responsible for the content and views expressed in this publication and they do not necessarily represent the decisions, policy or views of the WHO.

J.G. was supported by a bursary from the Undergraduate Research Support Scheme at the University of Warwick.

Author contributions: J.G. and F.P.C. developed the idea and designed the protocol, J.G. and E.G. carried out data extraction, M.A.M. and F.P.C. helped with searches and protocol implementation, J.G. carried out data analysis and drafted parts of the article. C.J. supported statistical analysis, E.G., C.J., M.A.M. critically revised the draft article, F.P.C. supervised the study, helped with analysis, drafted parts of the article. F.P.C. is the guarantor.

Conflicts of interest

F.P.C. is a technical advisor to the WHO, Director of the WHO Collaborating Centre, unpaid member of Action on Salt and WASH. J.G., E.G., C.J., M.A.M. have no conflict of interest to declare.

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