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Review

The Effect of Non-Oil Seed Legume Intake on Blood Pressure: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

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ABSTRACT

Hypertension is a primary modifiable risk factor for CVD, whereby even small reductions in blood pressure (BP) can decrease risk for CVD events. Modification of dietary patterns is an established, nonpharmacologic approach for the prevention and management of hypertension. Legumes are a prevailing component of dietary patterns associated with lower BP in observational research, but there is a need to understand the effects of legume consumption on BP. This study aimed to synthesize evidence from randomized controlled trials (RCTs) for the effects of non-oil seed legume consumption on systolic blood pressure (SBP) and diastolic blood pressure (DBP) (PROSPERO registration: CRD42021237732). We searched CINAHL, Cochrane, Medline, and PubMed scientific databases from inception through November 2022. A random-effects meta-analysis was conducted to assess the mean differences (MDs) for each outcome variable between legume-based and comparator diets. This review included 16 RCTs and 1092 participants. Studies ranged in duration (4–52 wk), participant age (17–75 y), and weekly legume dose (450–3150 g) in whole or powdered form. No significant overall effect between legume consumption and BP amelioration was observed in the meta-analysis (SBP—MD: −1.06 mm Hg; 95% CI: −2.57, 0.4410 mm Hg; $I^2 = 45\%$; DBP—MD: −0.48 mm Hg; 95% CI: −1.06, 0.10 mm Hg; $I^2 = 0\%$). The certainty of evidence was determined as low for SBP and DBP. Significant subgroup differences in SBP were found when studies were grouped according to participant BMI, with SBP reduction found for participants with overweight/obese BMI (MD −2.79 mm Hg, 95% CI: −4.68, −0.90 mm Hg). There is a need for large, high-quality trials to clearly define the benefits and mechanisms of legume consumption in BP management. Consideration of the relevance in individuals with obesity, overweight, and hypertension may also be warranted.

This trial was registered at PROSPERO as CRD42021237732.

Keywords: legume, blood pressure, hypertension, systematic reviews, meta-analysis, dietary pulses, dietary guidelines

Statement of Significance

Legumes are a prevailing component of healthy dietary patterns shown to ameliorate blood pressure. To our knowledge, this is the most recent and comprehensive review to synthesize and critically evaluate this aggregate body of evidence, with consideration of subgroup populations, intervention dose, form, and duration and highlights the future research needed in individuals with obesity, overweight, and hypertension.

Introduction

Hypertension [systolic blood pressure (SBP) ≥140 mm Hg or diastolic blood pressure (DBP) ≥90 mm Hg] is considered the primary modifiable, metabolic risk factor for CVD [1]. Elevated blood pressure (BP) accounts for almost a quarter of the population-attributable fraction for CVD and mortality in countries worldwide, regardless of the income level [2]. Hypertension

Abbreviations: BP, blood pressure; CAD, coronary artery disease; CVD, cardiovascular disease; DBP, diastolic blood pressure; GRADE, Grading of Recommendations, Assessment, Development and Evaluation; IHD, ischemic heart disease; MD, mean difference; NOS, non-oil seed; RCT, randomized controlled trials; ROB, risk of bias; SBP, systolic blood pressure; T2DM, type 2 diabetes mellitus; TLC, therapeutic lifestyle change.

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attributes to 54% of all stroke incidences and 47% of all coronary artery disease (CAD) [3]. Studies show that a reduction in BP can rapidly decrease CAD risk by a quarter, notwithstanding the presence or absence of existing CVD or elevated BP [4]. A 10-mm Hg decrease in SBP or 5-mm Hg decrease in DBP correlates with a reduction in both stroke (30%) and heart failure (25%) risks [4]. In normotensive individuals, even a 2-mm Hg decrease in normal SBP is associated with a risk reduction for stroke (10%) and ischemic heart disease (IHD) (7%) [5,6]. Considering its effect on health, exacerbated by increasing prevalence with age and obesity [7], elevated BP has emerged as a principal area of interest for the health of populations and a leading contributor to the global burden of diseases [5,8].

Although there are numerous pharmacologic treatments for hypertension, there is substantial evidence supporting the modification of dietary patterns and specific nutritional elements for the prevention and management of BP [9,10]. Indeed, the dietary approach may not only be more accessible and affordable than pharmacologic interventions but also potentially have far reaching health benefits associated with optimal BP control [6, 11]. For instance, the Mediterranean diet and DASH diet are low in energy density, rich in fruits, vegetables, low-fat dairy, legumes, and nuts, and significantly lower in sodium content in comparison with a Western diet [12]. These dietary characteristics are paralleled by the increased concentrations of protective nutrients such as fiber, magnesium, and potassium [12–14]. The BP-lowering effects of such diets have been elucidated as an effective nutritional strategy for hypertension [12,15], shown to reduce SBP by 7.1 mm Hg [16] and DBP by 2.6 mm Hg [12], and may be further enhanced by macronutrient manipulation, such as the substitution of carbohydrates for protein [17]. Similarly, the New Nordic Diet, a plant-based diet that promotes the consumption of whole grains, legumes, fruits, and vegetables, has been shown to significantly decrease BP (SBP by 5.1 mm Hg and DBP by 3.2 mm Hg) [18,19].

To inform dietary guidelines and other dietary strategies, it is valuable to understand the key components of these diets and their potential for BP management. As a prevailing component of healthy dietary patterns, legumes are a rich source of nutrients that are associated with the amelioration of high BP [20–22], including lower GI carbohydrate, potassium, magnesium, folate, polyphenols, unsaturated fatty acid [22,23], and dietary fiber (soluble, insoluble, and resistant starch) concentrations [24]. Evidence indicates that a 17-g daily increase in dietary fiber correlates with a significant reduction in total BP (1.15 mm Hg in SBP and 1.65 mm Hg in DBP) [25]. Furthermore, legumes are a rich source of plant protein with a unique amino acid profile assumed to impart significant BP-lowering effects, such as vasodilation, owing to their high arginine content [26,27] and angiotensin-converting enzyme inhibitory activity [28]. A secondary analysis of data from the National Health and Nutrition Examination Survey 1999–2002 determined that regular consumption of a variety of legumes provided consumers with a favorable nutrient intake and improved satiety, concurrent with a reduced risk for obesity, hypertension, and hypertension-related disorders such as CVD and CAD [29].

The findings of a recent systematic review and meta-analysis of prospective cohort studies evaluating the association between legumes and cardiometabolic diseases, supports the promotion of increased legume consumption for the prevention of such conditions. However, the study concluded that the available evidence is, at best, weak and the pivotal significance of the effects of legume intake on BP, inconclusive [30].

This review builds on a previous systematic review and meta-analysis of controlled feeding trials, which evaluated 8 randomized controlled trials (RCTs), published between 2009 and 2012, examining the effects of non-oil seed (NOS) legumes on BP [31]. This previous review concluded that although there was significant evidence for the promotion of legume consumption in the amelioration of elevated BP, there were a multitude of limitations to the included studies, highlighting a need for superior quality, large-scale trials to consolidate these findings [31]. There are numerous critical challenges that undermine the translatability of dietary intervention findings into clinical practice, such as study design, methodology, high clinical heterogeneity, inadequacy of outcome measures, and low adherence rates [32]. Therefore, this study aimed to examine all available evidence from RCTs on the effects of the consumption of NOS legumes on BP and to describe the certainty of evidence base. This may serve to provide evidence for the development of future dietary guidelines. To our knowledge, this is the most recent review to synthesize and critically evaluate this aggregate body of evidence, with consideration to population subgroups, intervention dose, form, and duration.

Methods

Study protocol

This systematic review and meta-analyses followed the Cochrane Handbook for Systematic Reviews of Interventions guidelines [33] and is reported in accordance with the PRISMA guidelines [34]. The protocol was preregistered in the International Prospective Register of Systematic Reviews (PROSPERO) [35] (https://www.crd.york.ac.uk/prospero; registration number CRD42021237732.

A systematic search of 4 scientific databases CINAHL (through EBSCO), Medline (through EBSCO), PubMed, and Cochrane CENTRAL was conducted from their inception to 3 November, 2022, to identify published interventions that examined the effect of NOS legume consumption on BP in adults. Free-text search terms and relevant controlled vocabulary terms that related to legumes and BP were used (lupin OR legume OR bean OR lentil OR chickpea OR mung OR pea OR non-oil seed legumes OR lens culinaris OR cicer arietinum OR garbanzo OR phaseolus vulgaris) AND (blood pressure OR diastolic pressure OR pulse pressure OR systolic pressure OR hypertension OR arterial pressure OR aortic pressure OR aortic tension OR arterial tension). Full search terms are reported in Supplemental Table 1.

Inclusion criteria

Eligible studies were required to meet the inclusion criteria as follows: *1*) RCTs (parallel and crossover) that investigated the effects of NOS legume consumption on BP; *2*) human participants (males and/or females) aged ≥18 y; *3*) legumes consumed in whole form (sprouted, cooked, and raw) or powders/flours where all components of the legume are contained; *4*) intervention duration of ≥3 weeks, considered the minimum period required for evaluating the effect of an intervention [36]; *5*) measured BP (SBP and DBP); and *6*) published in English.

Exclusion criteria

Exclusion criteria were applied as follows: *1*) intervention involves oil seed legumes (soy and peanut) or the isolated components of legumes (fiber, protein, and isoflavones) owing to differences in their physicochemical properties, nutritional profile, and potential for confounding effects on BP; *2*) pre-existing renal disease (chronic kidney disease stages 3–4); and *3*) trials where consumption of legumes could not be isolated as the intervention, within the context of healthy dietary patterns such as Mediterranean or DASH diets. There were no restrictions regarding other pre-existing conditions, BMI, or ethnic background. Although a previous systematic review was conducted through to 2012, no restriction was set on the date of publication to ensure all relevant studies could be synthesized in this review.

Study selection

All identified articles were exported to Covidence (Covidence System Review Software; 2019; Veritas) for screening and full-text review of articles. After the removal of duplicates, screening based on title and abstract was conducted by 2 independent authors (GLR and EJB), against the predefined eligibility criteria. In the case that an abstract was not available or insufficient, the full text was retrieved and examined to enable the reviewer to decide on the article's eligibility. Remaining articles were progressed for full-text review, conducted independently by 2 authors (GLR and EPN), for the analysis against eligibility criteria. Articles were further assessed for duplication across study population, and where trial results had been reported across multiple studies, only those reporting eligible outcomes were included. In addition, the reference lists of eligible articles were reviewed for potentially relevant articles. Conflicts regarding inclusion/exclusion of an article were resolved through consensus.

Data extraction

Data extraction was performed by a single author (GLR) in consultation with the research team and tabulated as follows: author, published year, country, and funding; study design (crossover/parallel and blinding) and analysis (intention-to-treat); duration; primary outcome; sample size and attrition; inclusion criteria; population (sex and age); details of intervention (legume type, form, and dose) and comparator diets; dietary assessments used; and BP measurement. Where legume dose was reported as a serve or cup, these values were converted to grams per week. Attempts to contact study authors were made to seek clarification or where data were missing from the publication.

Quality assessment and risk of bias

The methodologic quality of each included studies was independently assessed by 2 authors (GLR and EJB), using version 2 of the Cochrane risk of bias tool for randomized trials (RoB2.0) [37]. Final assessments were based on consensus between the authors.

Statistical analysis

A meta-analysis was conducted on each outcome variable (SBP and DBP) using RevMan5 [Review Manager (RevMan); Computer program; version 5.4.1; The Cochrane Collaboration, 2020]. The effect size was reported as the mean difference (MD) and 95% CIs. Data were extracted as mean change and SD where available. The final mean values and corresponding SDs were used where change was not available. Where SDs were not reported, the values were derived from the 95% CIs [38–40] and standard error [41–43] using the RevMan calculator [44]. In the case that a study included multiple legume intervention groups, these intervention groups were combined using the RevMan calculator. Owing to the broad variability in study methodology, random-effects models were applied to calculate the pooled effect size. Crossover trials were initially included in the meta-analysis, in the same way as parallel trials, by comparing measurements from the intervention periods with the control periods. Although this approach results in a unit-of-analysis error, it is considered a conservative approach [33]. In addition, sensitivity analyses were conducted using a paired analysis of crossover trials with a range of correlation coefficients (0.25, 0.5, and 0.75), to explore whether crossover studies were underweighted. Finally, subgroup analyses were conducted to explore the effect of legume consumption on BP in crossover trials compared with that in parallel trials. Statistical significance was set at $P \leq 0.05$, and between-study heterogeneity was assessed using I^2 and categorized according to Cochrane guidelines: low heterogeneity ($I^2 = 0\%$ to 40%); moderate heterogeneity ($I^2 = 30\%$ to 60%); substantial heterogeneity ($I^2 = 50\%$ to 90%); and considerable heterogeneity ($I^2 = 75\%$ to 100%) [33].

Sources of heterogeneity were explored by sensitivity and subgroup analyses. Sensitivity analyses (leave-one-out method) were performed to estimate the influence of each individual study on the overall pooled effect by omitting 1 study at a time with a recalculation of the summary of estimates. To investigate sources of heterogeneity, post hoc subgroup analyses were undertaken for study design (parallel/crossover), participant characteristics (sex and age), underlying health status [overweight/obese, type 2 diabetes mellitus (T2DM)], dietary intervention (hypocaloric and legume type and form, dose, and duration). Publication bias was investigated by the visual inspection of funnel plots and formal testing with the Egger's test [45].

Certainty assessment

The certainty of evidence was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach [46]. Evidence was graded by 2 independent authors (GLR and KL). The body of evidence of RCTs was graded as high level of evidence by default and downgraded based on the following 5 prespecified criteria: *1*) risk of bias (ROB) (assessed by Cochrane RoB2.0 [37]); *2*) inconsistency of results (substantial, unexplained and within-study heterogeneity); *3*) indirectness of evidence (external validity and limited generalizability); *4*) imprecision (small sample size and wide CIs); and *5*) publication bias (significant evidence of small study effects).

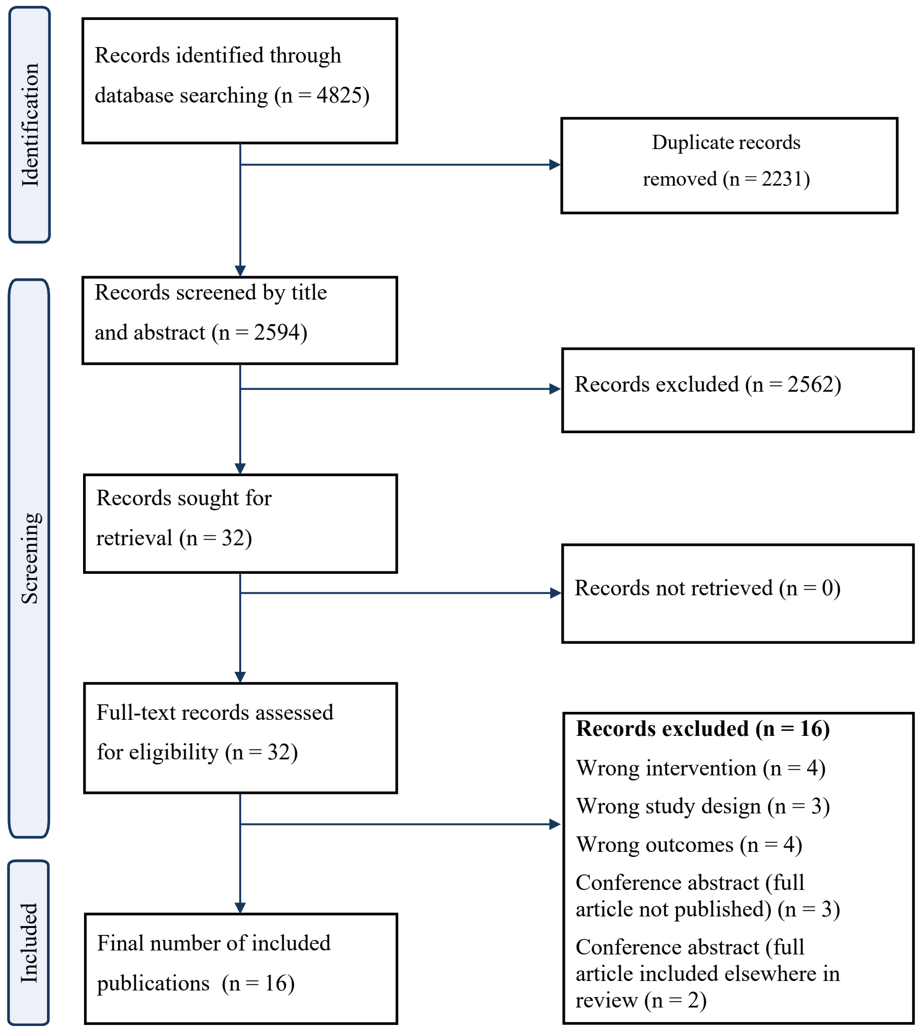

FIGURE 1. Screening and selection of randomized controlled trials on legume intake and blood pressure.

Results

Study selection

Figure 1 presents the PRISMA diagram of the full systematic search and selection of literature. Of the 4825 records identified from databases and manual searches, 2231 duplicates were removed. Of the 2594 records retrieved for title and abstract screening, 2562 were excluded due to failure to meet the eligibility criteria. A full-text review was conducted on 32 records, of which a further 16 studies were excluded due to failure to meet the eligibility criteria. Finally, 16 studies were included in the systematic review and meta-analysis.

Study characteristics

Table 1 provides a summary of study characteristics. Studies were conducted in Canada (38%) [39, 47–51], Iran (31%) [41–43,52,53], Australia (19%) [38,40,54], and Spain (13%) [55, 56]. Among the trials, 5 studies applied a crossover design [41,43, 47,51,54], whereas the remaining used a parallel design ($n = 11$; 69%) [38–40,42,48–50,52,53,55,56], and 5 studies incorporated some degree of blinding [38,47,49,51,54]. Study duration ranged from 4 [51] to 52 weeks [38], and most commonly, studies had an 8-week duration ($n = 7$; 44%) [41,47,50,52,54–56]. Nine studies used the intention-to-treat (ITT) approach to address bias in the original analysis [38–41,43,47,49,53,54], whereas the remaining studies did not detail participant numbers in the final analyses. All but 2 studies [42,56] explained the method of BP measurement used, with most using sphygmomanometer. Ten studies measured BP after a period of rest (range: 5–15 min) [39,41,43,47,48,50, 52–55], and 8 studies reported BP as a mean of 2 or more measures (range: duplicate to quadruplicate) [39,41,48,50–54]. Of the 16 included studies, BP was reported as the primary outcome variable in only 2 studies [40,53].

Participant characteristics

Sixteen studies involved 1288 randomly assigned participants, of which 1092 participants were accounted for at the end point. Sample sizes ranged from 17 [54] to 300 [53] participants. Participant ages ranged from 18 to 75 y, and most studies included both males and females; 3 recruited only females [42, 48,49], whereas 2 recruited only males [51,55]. Participant health status included overweight/obesity (n = 8; 50%) [38, 40–42,50,53,55,56], T2DM (n = 5; 31%) [39,41,52–54]; T2DM and overweight/obesity (n = 2) [41,53]; and healthy status (n = 2) [43,51].

Dietary interventions

The median duration of interventions was 8 weeks (range: 4–16 wk) with the exception of 1 study that continued for 52 weeks [38]. Although most of the interventions incorporated varied whole, cooked legumes, with a median weekly dosage of 700 g and a mean dosage of 1028 g (range: 450–3150 g), 3 studies used lupin kernel–enriched flour with a mean dose of 529 g (range: 30–924 g) [38,40,54]. One study tested the effect of 700 g/wk of 3 different dehydrated powdered legumes (chickpea, lentil, and green pea) against dehydrated potato flakes in the comparator diet [51] (Table 1). Most studies incorporated isocaloric foods or diets across both arms of the dietary treatment [38–42,48,52,54–56], and 5 included energy restriction (hypocaloric) as a component of both dietary treatment groups [42,50,53,55,56]. A single study compared an ad libitum legume-based diet against a hypocaloric diet [50]. Three studies assessed the effects of enriching healthy dietary patterns with legumes, such as the therapeutic lifestyle change (TLC) diet [41,49] and DASH diet [53]. Six studies required participants to consume provided meals [38,40,47–49,54], whereas 2 studies incorporated legumes into the usual diet [43,47] (Table 1).

ROB in individual studies

Overall, the ROB ranged from low to some concerns across the 16 included studies. Seven studies had a low ROB [38,43,47,49,51,53,54], with remaining 9 assessed as having some concerns [39–42,48,50,52,55,56], primarily owing to a lack of information for Domain 5, the analyses of results in accordance with prespecified analysis [37]. The Cochrane RoB2.0 assessment for each study (Supplemental Figure 1 and Supplemental Table 2) and the ROB graph (Supplemental Figure 2) are available in the Supplementary Material.

Effect of legume consumption on BP

The meta-analysis of the included studies revealed that, relative to the comparator diet, legume consumption showed small reductions in both SBP (MD: −1.06 mm Hg; 95% CI: −2.57, 0.44) (Figure 2) or DBP (MD: −0.48 mm Hg; 95% CI: −1.06, 0.10) (Figure 3), although they did not reach a statistical significance. There was evidence of significant moderate heterogeneity in the analysis of SBP (I^2 = 45%) and low, nonsignificant heterogeneity for DBP (I^2 = 0%).

Sensitivity and sensitivity analysis

Sensitivity analyses of crossover trials, using correlation coefficients of 0.25, 0.5, and 0.75, found overall similar results to the primary analysis (Supplemental Table 3). Subgroup analyses were conducted examining study design, duration, legume type, form, dosage, participant sex, age, and health status. Significant subgroup differences in SBP were found when studies were grouped according to participant BMI (I^2 = 90.1%), with reductions in SBP only found for participants with overweight/obese BMI (MD: −2.79 mm Hg; 95% CI: −4.68, −0.90) (Figure 4). Sensitivity analyses did not modify the effect or heterogeneity for pooled estimates for treatment effects on SBP nor DBP. The results of subgroup analyses, including test for subgroup differences, are summarized in Table 2.

Publication bias

The visual inspection of funnel plots and results for the Egger test did not indicate small study effects for SBP (bias: 0.211; 95% CI: −0.932, 1.354) (Supplemental Figure 3) or DBP (bias: 0.333; 95% CI: −0.553, 1.218) (Supplemental Figure 4).

Certainty of evidence

In accordance with GRADE guidelines [46], the certainty of evidence was determined as low for both SBP and DBP, owing to the downgrade for ROB and imprecision (Supplemental Table 4).

Discussion

This review of 16 RCTs (1092 participants) extends the findings of the previous review [31] by an additional 8 studies. In this review, the certainty of evidence was determined as low for SBP and DBP. The evidence suggests that legumes consumption results in little to no difference in BP outcomes (SBP or DBP) [57], although there was some evidence of a reduction in SBP in participants who were overweight or obese. However, our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect [58].

	Legume diet			Comparator diet				Mean Difference
Study or Subgroup	Mean [mm Hg]	SD [mm Hg]	Total	Mean [mm Hg]	SD [mm Hg]	Total	Weight	IV, Random, 95% CI
Abete 2009	115.2	8.1	8	114.5	8.6	10	3.2%	0.70 [-7.04, 8.44]
Abeysakara 2012	123	15	87	121	13	87	7.7%	2.00 [-2.17, 6.17]
Alizadeh 2014	111.3	14.4	17	125.6	9.9	17	2.8%	-14.30 [-22.61, -5.99]
Belski 2011	119.6	2.5	46	120.9	2.7	47	17.5%	-1.30 [-2.36, -0.24]
Gravel 2010	119.3	11.4	60	117.1	13.2	54	6.9%	2.20 [-2.35, 6.75]
Hassanzadeh-Rostami 2019	-3.5	13.2	20	-6.5	10.9	23	3.5%	3.00 [-4.30, 10.30]
Hermsdorff 2011	106	10	15	111	12	15	3.0%	-5.00 [-12.90, 2.90]
Hosseinpour-Niazi 2015	-4	16.7	31	-4	16.7	31	2.8%	0.00 [-8.31, 8.31]
Hosseinpour-Niazi 2022	-9.9	10.5	150	-6.1	11	150	12.7%	-3.80 [-6.23, -1.37]
Jenkins 2012	118	9.7	60	118	11.6	61	8.6%	0.00 [-3.81, 3.81]
Kazemi 2018	-3	8	31	-5	8	30	8.1%	2.00 [-2.02, 6.02]
Lee 2009	120	5.7	37	123	5.7	37	12.2%	-3.00 [-5.60, -0.40]
Mollard 2012	106.7	11.3	19	111.3	14.2	21	3.0%	-4.60 [-12.52, 3.32]
Saraf-Bank 2016	109	13.1	26	107.7	14.1	26	3.4%	1.30 [-6.10, 8.70]
Veenstra 2010	125.5	17.2	19	125.4	10.4	21	2.5%	0.10 [-8.82, 9.02]
Ward 2020	127	16.5	17	124	12.4	17	2.1%	3.00 [-6.81, 12.81]
Total (95% CI)			**643**			**647**	**100.0%**	**-1.06 [-2.57, 0.44]**

Heterogeneity: Tau² = 3.08; Chi² = 27.31, df = 15 (P = 0.03); I² = 45%
Test for overall effect: Z = 1.38 (P = 0.17)

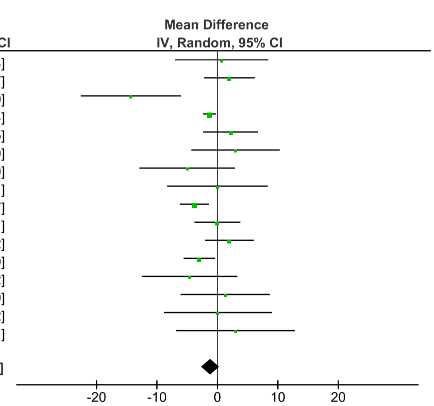

FIGURE 2. Forest plot showing the mean difference and 95% CIs of the overall effect of legume intake on systolic blood pressure in 16 randomized controlled trials, pooled by using random-effects model.

Study or Subgroup	Legume diet Mean [mm Hg]	Legume diet SD [mm Hg]	Legume diet Total	Comparator diet Mean [mm Hg]	Comparator diet SD [mm Hg]	Comparator diet Total	Weight	Mean Difference IV, Random, 95% CI
Abete 2009	75.3	6.2	8	72.5	8.5	10	0.7%	2.80 [-4.00, 9.60]
Abeysakara 2012	78	8	87	76	9	87	5.3%	2.00 [-0.53, 4.53]
Alizadeh 2014	76.1	8.7	17	79.2	9.5	17	0.9%	-3.10 [-9.22, 3.02]
Belski 2011	73.3	2	46	74.3	2	47	50.9%	-1.00 [-1.81, -0.19]
Gravel 2010	75.3	8.1	60	75.8	7.3	54	4.2%	-0.50 [-3.33, 2.33]
Hassanzadeh-Rostami 2019	-1.7	8.5	20	-5.4	11.5	23	0.9%	3.70 [-2.30, 9.70]
Hermsdorff 2011	70	6	15	72	10	15	1.0%	-2.00 [-7.90, 3.90]
Hosseinpour-Niazi 2015	-4	16.7	31	-4	11.1	31	0.7%	0.00 [-7.06, 7.06]
Hosseinpour-Niazi 2022	-2.4	8	150	-2.3	6.9	150	11.8%	-0.10 [-1.79, 1.59]
Jenkins 2012	69	7.7	60	70	9.7	61	3.5%	-1.00 [-4.12, 2.12]
Kazemi 2018	-3	7	31	0	7	30	2.7%	-3.00 [-6.51, 0.51]
Lee 2009	71.6	3.5	37	71	3.5	37	13.2%	0.60 [-0.99, 2.19]
Saraf-Bank 2016	75	9.1	26	74	7.4	26	1.7%	1.00 [-3.51, 5.51]
Veenstra 2010	77	8.3	19	78.1	7.4	21	1.4%	-1.10 [-5.99, 3.79]
Ward 2020	74	8.2	17	75	8.2	17	1.1%	-1.00 [-6.51, 4.51]
Total (95% CI)			**624**			**626**	**100.0%**	**-0.48 [-1.06, 0.10]**

Heterogeneity: Tau² = 0.00; Chi² = 13.55, df = 14 (P = 0.48); I² = 0%
Test for overall effect: Z = 1.61 (P = 0.11)

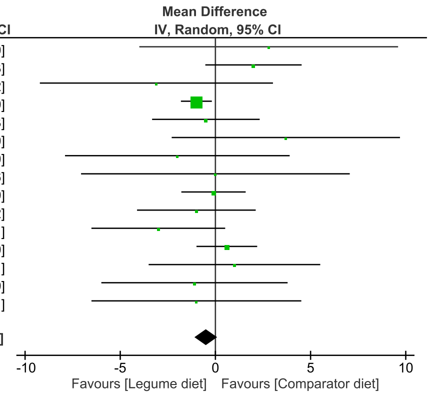

FIGURE 3. Forest plot showing the mean difference and 95% CIs of the overall effect of legume intake on diastolic blood pressure in 15 randomized controlled trials, pooled by using random-effects model.

Significant moderate heterogeneity was observed only for SBP (Figure 2). These findings are in contrast to the previous review [31], which found that legume consumption significantly reduced SBP (MD:−2.25 mm Hg; 95% CI: −4.22, −0.28), although DBP was nonsignificantly reduced (MD: −0.74 mm Hg; 95% CI: −1.74, 0.31). In addition, the previous review [31] observed significant between-study heterogeneity for both SBP ($I^2 = 73\%$) and DBP ($I^2 = 58\%$).

Notably, half (8/16) of the studies included in this review reported that legume consumption had a significant ameliorating effect on ≥1 component of BP. Evidence suggests that study design and duration influence BP reductions in nutrition interventions [59]. Dong et al. [59] posit that a 12-wk study duration is associated with significant BP reductions. Furthermore, in crossover trials, the short duration of washout periods may not be sufficient to eliminate residual effects on potential BP reductions, thus suggesting that parallel trials may be better suited to such interventions. In this review, most of the interventions (63%) included a study duration of <12 wk, although no significant differences between the study durations were observed in our subgroup analysis.

A 2022 review of the population-based study, European Prospective Investigation into Cancer and Nutrition (EPIC)-Norfolk [60], found that higher legume intake was associated with significantly lower odds of hypertension in all participants (43% reduced risk) and particularly in women (68% reduced risk) [61], warranting dietary guidance to increase daily legume intake to ≥55 g as a means to reducing the burden of hypertension and CVD [61]. In this review, all included studies, except 1 [54], used higher weekly doses, than those recommended in

Study or Subgroup	Legume diet Mean	Legume diet SD	Legume diet Total	Comparator diet Mean	Comparator diet SD	Comparator diet Total	Weight	Mean Difference IV, Random, 95% CI
1.13.1 Overweight/ Obese								
Abete 2009	115.2	8.1	8	114.5	8.6	10	3.2%	0.70 [-7.04, 8.44]
Alizadeh 2014	111.3	14.4	17	125.6	9.9	17	2.8%	-14.30 [-22.61, -5.99]
Belski 2011	119.6	2.5	46	120.9	2.7	47	17.5%	-1.30 [-2.36, -0.24]
Hermsdorff 2011	106	10	15	111	12	15	3.0%	-5.00 [-12.90, 2.90]
Hosseinpour-Niazi 2015	-4	16.7	31	-4	16.7	31	2.8%	0.00 [-8.31, 8.31]
Hosseinpour-Niazi 2022	-9.9	10.5	150	-6.1	11	150	12.7%	-3.80 [-6.23, -1.37]
Lee 2009	120	5.7	37	123	5.7	37	12.2%	-3.00 [-5.60, -0.40]
Mollard 2012	106.7	11.3	19	111.3	14.2	21	3.0%	-4.60 [-12.52, 3.32]
Saraf-Bank 2016	109	13.1	26	107.7	14.1	26	3.4%	1.30 [-6.10, 8.70]
Subtotal (95% CI)			**349**			**354**	**60.6%**	**-2.79 [-4.68, -0.90]**
Heterogeneity: Tau² = 2.86; Chi² = 15.19, df = 8 (P = 0.06); I² = 47%								
Test for overall effect: Z = 2.90 (P = 0.004)								
1.13.3 Mixed BMI status								
Abeysakara 2012	123	15	87	121	13	87	7.7%	2.00 [-2.17, 6.17]
Gravel 2010	119.3	11.4	60	117.1	13.2	54	6.9%	2.20 [-2.35, 6.75]
Hassanzadeh-Rostami 2019	-3.5	13.2	20	-6.5	10.9	23	3.5%	3.00 [-4.30, 10.30]
Jenkins 2012	118	9.7	60	118	11.6	61	8.6%	0.00 [-3.81, 3.81]
Kazemi 2018	-3	8	31	-5	8	30	8.1%	2.00 [-2.02, 6.02]
Veenstra 2010	125.5	17.2	19	125.4	10.4	21	2.5%	0.10 [-8.82, 9.02]
Ward 2020	127	16.5	17	124	12.4	17	2.1%	3.00 [-6.81, 12.81]
Subtotal (95% CI)			**294**			**293**	**39.4%**	**1.56 [-0.34, 3.45]**
Heterogeneity: Tau² = 0.00; Chi² = 1.14, df = 6 (P = 0.98); I² = 0%								
Test for overall effect: Z = 1.61 (P = 0.11)								
Total (95% CI)			**643**			**647**	**100.0%**	**-1.06 [-2.57, 0.44]**

Heterogeneity: Tau² = 3.08; Chi² = 27.31, df = 15 (P = 0.03); I² = 45%
Test for overall effect: Z = 1.38 (P = 0.17)
Test for subgroup differences: Chi² = 10.15, df = 1 (P = 0.001), I² = 90.1%

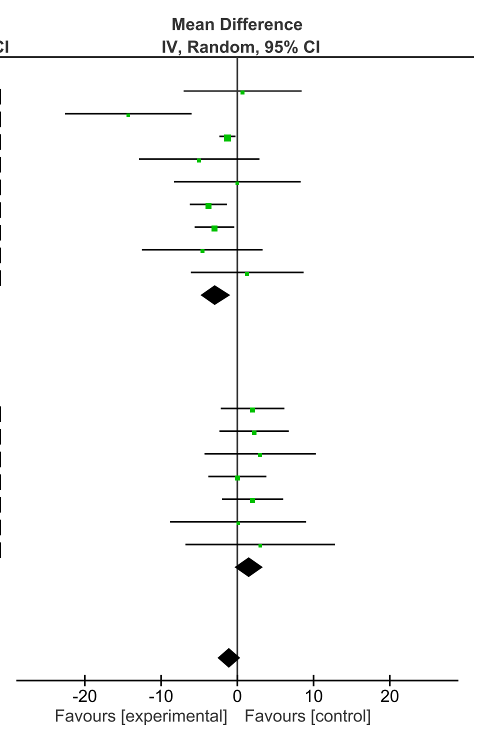

FIGURE 4. Forest plot showing the mean difference and 95% CIs of the subgroup analysis for the effect of legume intake on blood pressure in overweight, obese individuals, pooled by using the random-effects meta-analysis.

TABLE 1

Study characteristics of the included randomized controlled trials examining the effect of legume intake on blood pressure

First author (year), country, funding	Study design (analysis)	Study duration (wk)	Primary outcome	Sample size (attrition)	Inclusion criteria	Sex, age[1] (y)	Intervention			Comparator diet	Dietary assessment	BP measure
							Diet	Type, form	Dose (g/wk)			
Abete et al. (2009) [55], Spain, Government, University	Parallel (not reported)	8	Weight loss	$N = 18$[2] I: 8; C: 10 (0%)	Male, OB	0% F 38 ± 7	Hypocaloric + high legume intake One serve legumes, 4 d/wk. Avoid fatty fish, decrease animal protein. Hypocaloric: −30% EER Other diet treatments[3] Hypocaloric diet with fatty fish Hypocaloric high-protein diet	Mixed[4], Whole[5]	400–600[6]	Hypocaloric + animal protein. Lean meats, eggs, skimmed dairy. Omit legumes, fatty fish. Hypocaloric: −30% EER	3-d weighted FR (weeks 1 and 7); weekly session with dietician	Sphyg, seated before 5 min
Abeysekara et al. (2012) [47], Canada, Govt., Saskatchewan Pulse Growers	Crossover, SB, 4-wk washout (ITT analysis)	8	LDL-C	$N = 87$ (24%)	≥50 y, inactive	65% F[7] 59.7 ± 6.3	Legume-enriched diet 2 serves (250 g wet weight) of legumes daily as per supplied snacks, salads, soups, and meals. Rotated legume type	Mixed[4] Whole[5]	1750	Usual diet	110-item FFQ weeks 0 and 8; daily food log	Seated before 5 min
Alizadeh et al. (2014) [42], Iran, University	Parallel (not reported)	6	MetS	$N = 34$ I: 17; C: 17 (19%)	20–50 y, female, OB	100% F 36.1 ± 1.4	Hypocaloric diet enriched with legumes; Substitute meat with 2 serves (1 cup) legumes daily. Hypocaloric: −500 kcal/d	Mixed[4] Whole[5]	1680[8]	Hypocaloric diet without legumes (HDWL) Omit legumes. Increase animal protein 2 serves (60 g)/d. Hypocaloric: −500 kcal/d	3-d FR (weeks 0, 3, and 6); weekly sessions with a nutritionist	Not reported
Belski (2011) [38], Australia, Govt	Parallel, DB (ITT analysis)	52	Weight loss	$N = 93$ I: 46; C: 47 (29%)	20–71 y, OW/OB	44% F[7] 46.6 ± 9.7	Energy-restricted diet with lupin flour enriched Substitute products with supplied lupin kernel–enriched (25% to 40% lupin flour) breads, biscuits, pasta. Hypocaloric: −35% EER (12 wk)	Lupin kernel flour[9]	350[10]	Energy-restricted diet with wheat flour Substitute usual products with supplied whole-wheat flour breads, biscuits, pasta Hypocaloric: −35% EER (12 wk)	Fortnightly sessions with dietician for initial 12 wk. Weekly 3-d FR	Sphyg, mean 24-h ABPM
Gravel et al. (2010) [48], Canada, Pulse Canada	Parallel (ITT analysis)	16	MetS	$N = 114$ I: 60; C: 54 (14%)	30–65 y, female, ≥2 metabolic risk factors	100% F 47.5 ± 17.5	Legume-based meals 5 legume-based meals (750 mL)/wk, ad libitum. Supplied meals isocalorically matched to control meals	Mixed[4] Whole[5]	570[11]	Legume-free meals 5 legume-free meals/wk, ad libitum	Intake checklist, nutrient analysis; 3-d FR (weeks 0, 8, and 16)	Rested before 5 min, mean of 3

(*continued on next page*)

TABLE 1 (*continued*)

First author (year), country, funding	Study design (analysis)	Study duration (wk)	Primary outcome	Sample size (attrition)	Inclusion criteria	Sex, age[1] (y)	Intervention			Comparator diet	Dietary assessment	BP measure
							Diet	Type, form	Dose (g/wk)			
Hassanzadeh-Rostami et al. (2019) [52], Iran, University	Parallel (not reported)	8	Cardio-MetS	$N = 43$ I: 20; C: 23 (14%)	40–65 y, T2DM	72% F[7] 52.5 ± 12.5	Legume-based weight maintenance diet Replace meat with 2 serves (1 cup) legumes, 3 d/wk. Nonintervention days: eat chicken or fish, omit red meat, legumes Other diet treatment[3] Soybean-based weight maintenance diet	Mixed[4] Whole[5]	450[13]	Red meat-based weight maintenance diet[5] Two serves (60 g) red meat, 3 d/wk. Nonintervention days: eat chicken or fish, omit red meat, legumes	Weekly phone session; monthly visit; daily food checklist; 24-h FR (weeks 0, 4, and 8)	Sphyg, seated before 15 min, mean of 2
Hermsdorff et al. (2011) [56], Spain, Govt., University	Parallel (not reported)	8	Plasma CRP	$N = 30$ I: 15; C: 15 (0%)	OW/OB	43% F[7] 36.0 ± 8	Legume-based energy-restricted diet ($n = 15$) 7-d legume-based menu with 4 serves legumes/wk. Hypocaloric: −30% EER/d	Mixed[4] Whole[5]	640–940[14]	Legume-free energy-restricted diet ($n = 15$) 7-d legume-free menu. Hypocaloric: −30% EER/d	3-d weighed FR (weeks 0 and 8); weekly dietician session	As per WHO criteria [86]
Hosseinpour-Niazi (2015) [41], Iran, University	Crossover,4-wk washout (ITT analysis)	8	LDL-C	$N = 31$ (22%)	40–75 y, T2DM, OW	77% F[7] 58.1 ± 6.0	Legume-based, energy-reduced, TLC[15] diet TLC diet, replace 2 serves red meat with variety of legumes (1 cup) on 3 d/wk	Mixed[4] Whole[5]	450[13]	Legume-free energy-reduced, TLC[15] diet Omit legumes	Weekly 3-d FR and dietician sessions	Sphyg, seated before 15 min, mean of 2
Hosseinpour-Niazi (2022) [53], Iran, University	Parallel (ITT analysis)	16	Blood pressure	$N = 300$ I: 150; C: 150 (5%)	30–65 y, T2DM, OW/OB	57% F[7] 55.4 ± 7.0	Legume-based DASH diet DASH diet, substitute 1 serve red meat with 1 serve legumes ≥5 d/wk, reduce 1 serve bread on those days. Hypocaloric: −500 kcal/d	Mixed[4] Whole[5]	>550–625[16]	Traditional DASH diet Hypocaloric: −500 kcal/d	Fortnightly 3-d FR by dietician	Sphyg, rested before 15 min, mean of 2
Jenkins et al. (2012) [39], Canada, PURENet, Saskatchewan Pulse Growers	Parallel (ITT analysis)	12	HbA1c	$N = 121$ I: 60; C: 61 (8%)	T2DM, HbA1c: 6.5% to 8.5%	50% F[7] 59.5 ± 9.0	Low-GI legume-based diet Implement food checklist (15 g carbohydrate portions), consume 1 cup (190 g) legumes daily	Mixed[4] Whole[5]	1330	High wheat fiber diet Whole-wheat carbohydrate foods (cereals, breads, and brown rice)	7-d FR (weeks 0, 8, 10, and 12)	Sphyg, seated, mean of 3
Kazemi et al. (2018) [49], Canada, Govt., University,	Parallel, SB (ITT analysis)	16	Insulin resistance	$N = 61$	18–35 y, female, PCOS	100% F 26.5 ± 8.5	Low-GI legume-based diet	Mixed[4] Whole[5]	1260–3150	TLC[15] diet	24-h diet recall (weeks 0 and 16)	Sphyg and stethoscope

the

Saskatchewan Pulse Growers				I: 31; C: 30 (36%)			TLC diet for breakfast, snacks. Supplied legume-based meals (soups, salads, and mains) for lunch, dinner daily. 90–225 g[17] legumes/meal			Lean meat, poultry, and low-fat milk as protein sources. Omit legumes		
Lee et al. (2009) [40], Australia, not reported	Parallel (ITT analysis)	16	Blood pressure	$N = 74$ I: 37; C: 37 (16%)	20–70 y, OW/OB	65% F 57.9 ± 8.0	Lupin kernel flour-enriched bread–based diet Substitute 15% to 20% daily energy intake with supplied lupin kernel–enriched flour bread (4 × 40 g slice)	Lupin kernel flour[9]	942[18]	White bread–based diet Substitute 15% to 20% daily energy intake with supplied white bread (4 × 40 g slice)	Daily FR assessed by dietician fortnightly; modified FFQ (weeks 0 and 16)	Sphyg, mean 24-ABPM
Mollard et al. (2012) [50], Canada, Govt.	Parallel (not reported)	8	Risk factors for MetS	$N = 40$ I: 19; C: 21 (9%)	35–55 y, OW/OB	72% F[7] 45 ± 10	Legume-enriched ad libitum diet 5 supplied legume-based meals (salad, soup, and side dish) included into usual weekly diet, ad libitum. 1 cup legumes/meal. Hypocaloric: none	Mixed[4] Whole[5]	896[19]	Dietary counseling to reduce energy intake Individualized hypocaloric (−500 kcal/d) diet, portion control, reduced fat, sugar, alcohol. Increased fruit, vegetables	FR (weeks 1, 4, and 8); log of gastrointestinal discomfort	Rested before 5 min, mean of 2
Saraf-Bank et al. (2016) [43], Iran, University	Crossover, 2-wk washout (ITT analysis)	6	Serum lipid profile	$N = 26$ (0%)	First-degree relatives with diabetes	54% F[7] 50 ± 6.6	Legume-enriched diet Four packages (240 g) legumes/wk ad libitum as part of usual diet + recommendations to improve diet and lifestyle	Pinto bean, lentil Whole[5]	693[20]	Usual diet Recommen dations to improve diet and lifestyle	24-h FR, weeks 0, 2, 4, and 6	Sphyg, seated before for 5 min
Veenstra et al. (2010) [51], Canada, Pulse Canada, Saskatchewan Pulse Growers	Crossover, DB, PC, 4-wk washout (not reported)	4	Gastrointestinal function	$N = 19$ (26%)	19–40 y, male, BMI 20–30 kg/m^2	0% F 28.1 ± 5.9	Dehydrated legume powder Rehydrate legume powder (dw:100 g), incorporate into usual diet/foods, consume as a single serve	Mixed[4] Spray-dried powder	700[21]	Dehydrated potato flake Rehydrate potato flake (dw: 50 g/d), incorporate into usual diet/foods, consume as a single serve	Daily food diary, return empty treatment packages	Mean of 2
Ward et al. (2020) [54], Australia, RPH research foundation	Crossover, DB, 8-wk washout (ITT analysis)	8	Glycaemic control	$N = 17$ (23%)	40–70 y, T2DM (HbA1c ≤9%), BMI 18–35 kg/m^2	36% F 58.0 ± 6.6	Energy-matched lupin kernel–enriched foods Substitute 20% daily energy intake with	Lupin kernel flour[9]	315	Energy-matched wheat-based foods Substitute 20% daily energy	7-d FR for study duration; FFQ at the end of each diet treatment	A&D digital monitor, rested before 5 min, mean

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TABLE 1 (*continued*)

First author (year), country, funding	Study design (analysis)	Study duration (wk)	Primary outcome	Sample size (attrition)	Inclusion criteria	Sex, age[1] (y)	Intervention			Comparator diet	Dietary assessment	BP measure
							Diet	Type, form	Dose (g/wk)			
							study foods at breakfast, lunch daily, and dinner 3 d/wk (cereal, pasta, and bread) equivalent to ~45 g lupin kernel/d			intake with study foods at breakfast, lunch daily, and dinner 3 d/wk (cereal, pasta, and bread)		of 4 (mane, nocte)

ABPM, ambulatory blood pressure monitoring; BP, blood pressure; C, control; DB, double blind; DW, dry weight; EER, estimated energy requirement; FR, food record; Govt., government; I, intervention; ITT, intention-to-treat; MetS, metabolic syndrome; OB, obesity; OW, overweight; PC, placebo controlled; PCOS, polycystic ovarian syndrome; SB, single blind; SBP, systolic blood pressure; Sphyg, sphygmomanometer; T2DM, type 2 diabetes mellitus; TLC, therapeutic lifestyle change.

[12]Value refers to the total number of participants in the control and nonsoy legume groups. Participants in soy legume group have been excluded for irrelevance (total participants across 3 diet treatments, $n = 75$).

[1] Age is presented as mean ± SD.

[2] Value refers to the total number of participants in the control and legume-based groups. Participants in other diet groups were excluded for irrelevance (total participants across 4 diet treatments, $n = 35$).

[3] Cointerventions have been listed; however, they were not included in the comparison or analysis in this review.

[4] The term mixed encompassed a variety of legumes, where the study authors did not specify.

[5] The term whole encompassed legumes in the following forms: whole, cooked, or canned and incorporated directly into meal/diet.

[6] Dose provided in serves and converted to grams, as derived from an estimation provided by study authors [55], where 1 serve is equivalent to 100–150 g cooked legumes. Value is the approximated average, over a 1-wk period (4 serves/wk).

[7] Final percentage of female participants analyzed at the end point.

[8] Dose provided in cups and converted to grams, as derived from an estimation provided by study authors [42], where 1 cup is equivalent to 240 g cooked legumes. Value is approximated over a 1-wk period (7 cups/wk).

[9] The term flour refers to cooked and dehydrated legumes incorporated into flour for use in baked goods.

[10] Value is an average weekly dose derived from an estimation provided by study authors [38] as >50 g lupin kernel/d (7 d/wk).

[11] Dose provided in milliliters and converted to grams, as derived from an estimation provided by study authors [87] where 1 mL is equivalent to 0.76 g cooked legumes. Value is approximated over a 1-wk period (5 meals/wk).

[13] Dose provided as a serve of legumes consumed as a meat substitute, where 1 serve or 1 cup was equivalent to 150 g [88].

[14] Dose range provided as 160–235 g per serve in accordance with individual's daily energy intake. Value is approximated over a 1-wk period (4 serves/wk).

[15] The National Cholesterol Education Program recommends the TLC diet to reduce cardiometabolic risk factors [89].

[16] Dose provided in serves converted to grams, as derived from an estimation provided by study authors [53], where 1 serve is equivalent to 110–125 g cooked legumes. Value is approximated over a 1-wk period (5 serves/wk).

[17] Kazemi et al. [49] based the quantity of specific legumes, included in each meal, on values shown to reduce insulin, blood glucose, and lipid concentrations in previous studies.

[18] Daily value derived from the study by Jayalath et al. [31] and calculated as a weekly sum.

[19] Dose provided as a cup measure. Weekly gram value was derived from an estimation provided by the study authors [50] where 5 cups were equivalent to 896 g cooked legumes.

[20] Dose provided as raw legumes (65 g/pack) and converted into cooked grams where 1 g raw legumes was equivalent to 2.66 g cooked legumes [56].

[21] Value refers to the dry weight of spray-dried, powdered legumes (100 g/d), being calculated as a weekly dose.

EPIC-Norfolk study [60]; however, our subgroup analysis did not demonstrate significant differences between the doses. Nutritionally, legumes are equally rich in protein and dietary fiber [62], both of which are considered important components of the BP-lowering effects of legumes [63,64]. Daily consumption of 12 g dietary fiber is associated with a 1-mm Hg decrease in SBP and 1.2-mm Hg decrease in DBP in individuals with normotensive or slightly elevated BP and further magnified in hypertensive individuals aged >40 y [65]. In consideration of the complementary role of fiber in the diet, a study assessed the BP-ameliorating effects of a high-fiber, high-protein diet compared with those of a high-protein diet. The findings demonstrated an additional 4.7 mm Hg reduction in SBP and an additional 1 mm Hg reduction in DBP [63]. Analogously, in this review, Lee et al. [40] increased the daily fiber intake by 13 g and demonstrated a 3-mm Hg reduction in SBP in the lupin-enriched intervention diet. These results equate to a lower risk of both stroke and IHD (10% and 7%, respectively) [5,6]. It is worth noting that the nutritional composition of legumes broadly varies between the legume types [66], and the effects of cooking methods further alter protein, fiber, and micronutrient content [67]. Clinical heterogeneity was observed across the included studies, suggesting future studies are warranted to scrutinize the BP-lowering potential of legumes based on the duration, dose, and specific legume types, whereas considering the methods by which legumes are prepared and cooked [32].

Excess central adiposity and obesity are major risk factors for hypertension, accounting for <65% of primary hypertension cases [68]. Excessive weight gain is positively associated with elevated BP, evidenced by a 4-mm Hg increase in SBP for each 4.5-kg increase in weight [69]. Individuals in the highest BMI quartile demonstrate significantly higher SBP (16 mm Hg) and DBP (9 mm Hg) than those in the lower quartile [69]. Obesity-related hypertension represents an expanding health concern affecting health care systems, worldwide [70]. As part of a therapeutic approach, dietary modification to include foods rich in fiber, lean protein, and antioxidants, whereas restricting saturated fats and sodium, is considered useful in the management of obesity and the potential mechanisms of obesity-related hypertension [71,72]. We observed a significant reduction in SBP (−2.8 mm Hg) in our subgroup analysis of individuals with overweight/obese BMI; although this finding may be clinically significant in reducing risk for stroke and IHD, it is, by nature, entirely observational and must be interpreted with caution [33].

Energy-restricted diets associated with weight loss, have been shown to rapidly decrease BP, particularly SBP, because DBP reduction may take longer [9,29,73]. Studies posit that a modest weight loss of 3.5 kg in normotensive individuals is accompanied by a reduction in SBP (5.8 mm Hg) and DBP (3.2 mm Hg) [74, 75]. Although legumes are effective for weight management in energy-restricted diets, owing to their satiety-inducing components [55], our subgroup analyses of studies incorporating a hypocaloric dietary component did not suggest a differing effect compared with studies incorporating legumes into the usual diet.

Dietary patterns involve complex biochemical interactions that synergistically and antagonistically affect health [76]. Dietary guidelines advocate diet modification as a primary factor for the prevention and management of hypertension. Indeed, nuts, legumes, and wholegrains are the food groups shown to be most effective in the primary prevention of metabolic disturbances and hypertension [77,78]. Nevertheless, the emphasis is on healthy dietary patterns over individual nutrients or foods, and consumption of these food groups, in addition to fruits and vegetables, paralleled by avoidance of foods high in saturated fat and sodium [9,16], are well represented in dietary patterns shown to ameliorate BP, such as the DASH, Mediterranean, and TLC diets [9,79]. The BP-reducing effects of such diets may be further enhanced with dietary counseling and provided meals, particularly in older hypertensive adults [80]. Included in our meta-analysis, Hosseinpour-Niazi et al. [53] implemented a DASH diet enriched with legumes and found higher legume intake (>96 g/d) was associated with a significant reduction in SBP. Furthermore, of the 2 studies that implemented a TLC diet, Kazemi et al. [54] provided participants with legume-based meals and reported a significant reduction in DBP; however, caution in interpreting these findings is warranted given the small sample size and limited generalizability.

It should be noted that studies included in this review did not investigate the effect of legume intake on BP in individuals with hypertension, potentially masking the effects of legume consumtpion on BP. This is particularly pertinent given that other dietary interventions for BP, such as sodium reductions, have been found to be more effective in individuals with hypertension. This may partly explain the greater reduction in BP in participants with overweight/obese BMI status. Although the studies included in this review did not have diagnosed hypertension, individuals with overweight/obese BMI status may be at an increased CVD risk and, therefore, experience a greater response to legume consumption [81].

As highlighted, there are several plausible explanations for why our findings did not reflect the epidemiological data, and to this point, we acknowledge several limitations to the current review. In RCTs, the primary outcome is closely correlated with the study design. Commonly, sample size calculations and reproducibility estimates are based on the primary outcome [82]. Alshamsi et al. [82] highlight the importance of building the study around a clinically relevant primary outcome to reduce bias; however, in this review, only 2 (12%) included studies defined BP as a primary outcome.

Dietary adherence to the diets was not assessed by biochemical markers; instead, studies used self-reported food records and 24-h recalls. These methods are prone to underreporting and random and systematic errors [83,84]. RCTs provide a high internal validity; however, translation of findings into clinical practice are commonly undermined by the complex nature of dietary interventions and challenges such as collinearity between dietary components, diverse dietary behaviors and food culture, and multitargeted interventional effects [32]. Nevertheless, there are several strengths to this study. First, this review provides a comprehensive account of the effect of legume consumption on BP based on the pooled evidence from 16 RCTs conducted across a range of geographical locations. In addition, the varied participant characteristics such as age, sex, baseline health status, and ethnicity may provide a degree of external validity and generalizability to our findings. Second, in

TABLE 2
The results of subgroup analyses according to key participant and study characteristics

Subgroup category	Subgroup	Systolic blood pressure				Diastolic blood pressure			
		No. of studies	No. of participants	Effect estimate MD (95% CI) (mm Hg)	Test for subgroup differences	No. of studies	No. of participants	Effect estimate MD (95% CI) (mm Hg)	Test for subgroup differences
Study design	Parallel	11	928	−1.63 (−3.40, 0.14)	$\chi^2 = 3.17$, $df = 1$;	10	888	−0.63 (−1.25, 0.00)	$\chi^2 = 2.54$, $df = 1$;
	Crossover	5	362	1.51 (−1.46, 4.48)	($P = 0.07$), $I^2 = 68.5\%$	5	362	0.94 (−0.88, 2.77)	($P = 0.11$), $I^2 = 60.6\%$
Study blinding	With blinding	5	402	−0.08 (−1.88, 1.71)	$\chi^2 = 1.61$, $df = 1$;	5	402	−0.63 (−2.18, 0.93)	$\chi^2 = 0.60$, $df = 1$;
	Without blinding	11	888	−1.92 (−4.11, 0.27)	($P = 0.20$), $I^2 = 37.8\%$	10	848	0.09 (−0.84, 1.03)	($P = 0.44$), $I^2 = 0\%$
Study duration (wk)	1–4	1	40	0.10 (−8.82, 9.02)	$\chi^2 = 0.14$, $df = 3$;	1	40	−1.10 (−5.99, 3.79)	$\chi^2 = 4.89$, $df = 3$;
	5–8	9	487	−1.28 (−4.75, 2.19)	($P = 0.99$), $I^2 = 0\%$	8	447	0.97 (−0.69, 2.63)	($P = 0.18$), $I^2 = 38.6\%$
	9–16	5	670	−0.98 (−3.42, 1.45)		5	670	−0.20 (−1.17, 0.78)	
	>16	1	93	−1.30 (−2.36, 0.24)		1	93	−1.00 (−1.81, −0.19)	
Sample size	$n < 50$	9	353	−1.76 (−5.32, 1.80)	$\chi^2 = 0.18$, $df = 1$;	8	313	−0.03 (−2.03, 1.98)	$\chi^2 = 0.07$, $df = 1$;
	$n \geq 50$	7	937	−0.91 (−2.51, 0.69)	($P = 0.67$), $I^2 = 0\%$	7	937	−0.32 (−1.23, 0.59)	($P = 0.79$), $I^2 = 0\%$
Participant sex	Males and females	11	1023	−1.52 (−2.75, −0.29)	$\chi^2 = 0.48$, $df = 2$;	10	983	−0.24 (−0.96, 0.49)	$\chi^2 = 1.72$, $df = 2$;
	Females only	3	209	−2.47 (−10.32, 5.38)	($P = 0.79$), $I^2 = 0\%$	3	209	−1.67 (−3.74, 0.40)	($P = 0.42$), $I^2 = 0\%$
	Males only	2	58	0.44 (−5.40, 6.29)		2	58	0.23 (−3.74, 4.20)	
Participant age	<40 y	3	135	−3.72 (−13.59, 6.16)	$\chi^2 = 0.29$, $df = 2$;	3	135	−2.49 (−5.07, 0.10)	$\chi^2 = 7.54$, $df = 2$;
	≥40 y	8	860	−0.98 (−2.97, 1.00)	($P = 0.86$), $I^2 = 0\%$	8	860	0.47 (−0.47, 1.41)	($P = 0.02$), $I^2 = 73.5\%$
	Mixed ages	5	295	−1.21 (−2.22, −0.19)		4	255	−0.93 (−1.70, −0.16)	
BMI status	Overweight/obese	9	703	−2.79 (−4.68, −0.90)	$\chi^2 = 10.15$, $df = 1$;	8	663	−0.56 (−1.20, 0.09)	$\chi^2 = 0.19$, $df = 1$;
	Mixed BMI	7	587	1.56 (−0.34, 3.45)	($P = 0.001$), $I^2 = 90.1\%$	7	587	−0.19 (−1.72, 1.34)	($P = 0.67$), $I^2 = 0\%$
Diabetes status	With diabetes	5	560	−1.00 (−3.85, 1.85)	$\chi^2 = 0.11$, $df = 2$;	5	560	−0.13 (−1.50, 1.24)	$\chi^2 = 0.46$, $df = 2$;
	Without diabetes	6	369	−1.39 (−2.39, −0.38)	($P = 0.95$), $I^2 = 0\%$	6	369	−0.65 (−1.34, 0.04)	($P = 0.79$), $I^2 = 0\%$
	Unspecified	5	361	−1.90 (−6.95, 3.15)		4	321	−0.38 (−3.22, 2.46)	
Legume type	Lupin, flour	3	201	−1.57 (−2.81, −0.34)	$\chi^2 = 0.34$, $df = 1$;	3	201	−0.46 (−1.64, 0.72)	$\chi^2 = 0.21$, $df = 1$;
	Mixed, whole	13	1089	−0.82 (−3.04, 1.39)	($P = 0.56$), $I^2 = 0\%$	12	1049	−0.10 (−1.09, 0.88)	($P = 0.65$), $I^2 = 0\%$
Legume dose, weekly (g)	≤450	4	232	−1.15 (−2.18, −0.11)	$\chi^2 = 1.17$, $df = 2$;	4	232	−0.91 (−1.70, −0.11)	$\chi^2 = 2.66$, $df = 2$;
	>450 to <1000	8	668	−2.26 (−4.00, −0.52)	($P = 0.56$), $I^2 = 0\%$	7	628	0.14 (−0.85, 1.14)	($P = 0.26$), $I^2 = 24.8\%$
	≥1000 g	4	390	−1.36 (−6.27, 3.55)		4	390	−0.79 (−3.37, 1.79)	
Intake frequency	1–4 d/wk	5	205	0.14 (−3.31, 3.59)	$\chi^2 = 0.51$, $df = 1$;	5	205	1.05 (−1.55, 3.66)	$\chi^2 = 1.22$, $df = 1$;
	≥5 d/wk	11	1085	−1.27 (−3.04, 0.49)	($P = 0.47$), $I^2 = 0\%$	10	1045	−0.47 (−1.18, 0.24)	($P = 0.27$), $I^2 = 17.8\%$
Dietary feature	Hypocaloric	6	515	−3.61 (−6.43, −0.79)	$\chi^2 = 5.02$, $df = 1$; ($P = 0.03$), $I^2 = 80.1\%$	5	575	−0.84 (−1.56, −0.12)	$\chi^2 = 2.83$, $df = 1$; ($P = 0.09$), $I^2 = 64.6\%$
	Usual diet	10	775	0.03 (−1.45, 1.50)		10	775	0.21 (−0.78, 1.19)	

comparison with the previous review [31], this meta-analyses included an additional 8 RCTs, enhancing the sample size and power to detect differences in the effect. Finally, potential sources of heterogeneity were explored through sensitivity and subgroup analyses, contributing to the robustness of our study.

Future research should focus on innovative study design with careful consideration for targeted population, definition of primary outcome, larger sample sizes, longer study duration, and focused efforts to address limitations such as adherence, blinding, and randomization [32,85].

In conclusion, this review systematically assessed the evidence from intervention studies investigating the effect of legume intake on BP. The certainty of evidence was deemed low for SBP and DBP. Legume intake did not have a significant overall effect on BP; however, significant subgroup differences in SBP were found when studies were grouped according to participant BMI, with reductions in SBP found only for individuals with overweight and obese BMI status. To improve the certainty of evidence, future research should focus on large-scale intervention trials, exploring differences in legume types, doses, and duration when considered in the context of healthy dietary patterns such as DASH and Mediterranean diets. Consideration of the relevance in individuals with obesity, overweight, and hypertension may also be warranted.

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Data availability

Data described in the manuscript, code book, and analytic code will be made available upon request.

Author disclosures

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Appendix A. Supplementary data

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