Review

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Scoping Review of Clinical Evidence for the Health Benefits of Culinary Doses of Herbs and Spices for Prevention and Treatment of Metabolic Syndrome

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Abstract: Metabolic syndrome is a growing global health problem. Evidence suggests that diets rich in phytochemical-containing herbs and spices can contribute to reduced risk of chronic disease. This review assesses the scope of evidence supporting the use of herbs and spices in the diet for prevention or treatment of metabolic syndrome and associated health conditions. A search of PubMed and Scopus databases was carried out to assess the available clinical or cohort evidence for culinary doses of commonly used herbs and spices. Trials that were measuring health factors related to metabolic disorders or the health of individuals with metabolic syndrome or associated diseases were included. Out of a total of 1742 papers identified, there were 146 relevant studies on black pepper, chilli, cardamom, cinnamon, coriander, cumin, fennel, fenugreek, garlic, ginger, Nigella seed, rosemary, sage and turmeric. No relevant research was found for cloves, mint, oregano, parsley or thyme. Cinnamon, fenugreek and ginger were the herbs/spices with the most published trials on them and showed promise for glycaemic control. Cardamom appears to have potential to reduce inflammatory markers, and cinnamon, ginger and turmeric for blood lipids. Patients with type 2 diabetes were the population most likely to be included in studies, but the preventative benefits of herbs/spices in healthy populations were also investigated, particularly for chilli, ginger and cinnamon. There is evidence for the beneficial effect of culinary doses of many common herbs/spices in the prevention and treatment of metabolic syndrome and associated disorders

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1. Introduction

Metabolic syndrome and associated conditions such as obesity, diabetes and cardiovascular disease are a growing global health problem. Between 2000 and 2019, global diabetes rates grew by more than 1.5% annually and prevalence rates for all other metabolic diseases also increased [1]. Poor diet and physical inactivity are risk factors for the development of metabolic syndrome and lifestyle changes are key for treatment [2].

Research indicates that the inclusion of herbs and spices in the diet, as is often the case in Mediterranean and Asian diets, may contribute to positive long-term health outcomes [3, 4]. Herbs and spices are a particularly rich source of phytochemicals and consumption of diets rich in phytochemicals have been linked with reduced risk of cardiometabolic disease and obesity [5, 6].

Many studies looking at the health benefits of herbs and spices use high-dose extracts; however, these do not reflect the main way that the general public might be able to take advantage of relatively cheap additions to the diet. Are these more expensive high-dose formulations necessary for everyone to benefit from herbs and spices, or do culinary doses provide benefit too?

Some research has begun to investigate this question. Clinical studies using herb and spice mixes to improve physiological responses to food have indicated that inclusion of herbs/spices in the diet may have preventative or therapeutic benefits [7-15]. The spice mixes used in these studies ranged in dose from 6g to 23.5g and positively impacted vascular function, blood glucose and insulin and blood lipids following meals. However, the reasons for the specific herb/spice mixes chosen and doses used

were often not explained. There is no consensus on whether dose matters for effect. Doses of 6g of Italian herb mixes [8], 23.5g of Asian spices [11] or a combination of Mediterranean herbs and Asian spices at doses of 14.5g [10] and between 0.5 and 6.6g [13, 14] have been found to have benefit. The lack of consistency in herb/spice mix formulation makes it challenging to attribute benefits to a particular herb/spice, combination of herb/spices or dose.

Zanzer et al assessed the effect of concentrated liquid extracts of individual spices but standardized to equal polyphenol content, enabling the different effects from each spice to be elucidated [15]. The dose of polyphenols provided from each extract corresponded to the amount found in 6g of cinnamon. Cinnamon and turmeric positively impacted on blood sugar levels, and turmeric reduced appetite, however, ginger and star anise did not have any effect. Therefore, individual effects from different herbs needs to be clarified.

The purpose of a scoping review is to highlight a body of evidence, explore how it has been reported on and identify evidence gaps [16]. It can also be used to inform development of future systematic reviews [17]. The many different types of evidence available for the health benefits of herbs/spices mean that identifying clear patterns in the research is challenging.

Therefore, the aim of this review was to assess the clinical evidence available for the metabolic health benefits of culinary doses of a range of common herbs and spices and to investigate whether there was consistency in the doses used and outcomes found. The most promising herbs and spices in the diet for specific health outcomes or populations can be identified, as well as what future clinical research is needed to confirm this effect.

2. Materials and Methods

A number of previous reviews have identified herbs/spices with evidence of benefit in health generally and metabolic syndrome and associated disorders more specifically [2, 3, 18-24]. These were assessed to determine a list of herbs/spices that were most likely to have adequate evidence for this scoping review: black pepper (*Piper nigrum* L.), cardamom (*Elletaria cardamomum* (L.) Maton), chilli (*Capsicum frutescens* L.), cinnamon (*Cinnamomum* sp), cloves (*Syzygium aromaticum* (L.) Merr. & L.M.Perry), cumin (*Cuminum cyminum* L.), fennel (*Foeniculum vulgare* Mill.), fenugreek (*Trigonella foenum-graecum* L.), garlic (*Allium sativum* L.), ginger (*Zingiber officinale* Roscoe), mint (*Mentha* sp), Nigella seed (*Nigella sativa* L.), oregano (*Origanum vulgare* L.), parsley (*Petroselinum crispum* (Mill.) Fuss), rosemary (*Salvia rosmarinus* Spenn.), sage (*Salvia officinalis* L.), thyme (*Thymus vulgaris* L.) and turmeric (*Curcuma longa* L.). A scoping review methodology was then used, referring to the preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews [25].

2.1. Search strategy

The PICO (population, intervention, comparison, outcome) strategy was used to formulate search terms. The research question was: do herbs and spices affect symptoms of metabolic syndrome in healthy or relevant diseased populations. Population was healthy individuals or those with metabolic syndrome and related disorders. Intervention was single herbs or spices at culinary doses. Comparison was a control or no treatment. Outcome was a change in metabolic syndrome symptoms or a change in metabolic biomarkers: blood glucose, lipids, insulin or inflammatory markers. PubMed and Scopus were searched in January 2023 with no date restrictions applied. A search of PubMed database was carried out using the search terms: (“black pepper" or "*Piper nigrum*" or "black seed" or "black cumin" or "*Nigella sativa*" or cardamom or "*Elettaria cardamomum*" or chilli or "*Capsicum frutescens*" or cinnamon or "*Cinnamomum zeylanicum*" or cloves or "*Syzygium aromaticum*" or coriander or "*Coriandrum sativum*" or cumin or "*Cuminum cyminum*" or fennel or "*Foeniculum vulgare*" or fenugreek or "*Trigonella foenum-graecum*" or garlic or "*Allium sativum*" or ginger or "*Zingiber officinale*" or mint or "*Mentha*" or oregano or "*Origanum vulgare*" or parsley or "*Petroselinum crispum*" or rosemary or "*Rosmarinus officinalis*" or sage or "*Salvia officinalis*" or thyme or "*Thymus vulgaris*" or turmeric or "*Curcuma longa*") AND (metabol* or diabetes or obesity or cardiovascular or "blood glucose" or "blood sugar" or "blood lipids" or "blood fats" or "blood insulin"). The results were filtered by Clinical Trial as article type. Each herb/spice was searched for separately in Scopus, with the following search term: TITLE-ABS-KEY ({herb/spice name}) AND TITLE-ABS-KEY (metabolic OR metabolism OR diabetes OR obesity OR cardiovascular) AND TITLE (clinical O

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R human). Additional studies were found using Google scholar and hand searching reference lists from relevant reviews.

2.2. Inclusion and exclusion criteria

The inclusion criteria were use of whole herb/spice or powdered/ground herb/spice in food, drinks or encapsulated and at doses that could reasonably be achieved in the diet without negatively impacting palatability. Concentrated extracts or oils and combinations of herbs or spices were excluded. Studies of water infusions or herbal teas were included when the formulation and quantity was what might be reasonably consumed at home. Any studies that administered herbal formulations or more than one herb/spice at a time were excluded, however, those with multiple individual herbs/spices being investigated in separate arms of the study were included. To ensure a broad range of different studies, clinical or cohort trials that were measuring health factors related to metabolic disorder or the health of individuals with metabolic disease or related conditions were included. Studies were included regardless of the age or health status of participants, as the intention was to determine the potential for herbs and spices to both prevent and treat metabolic disease. However, if the participants had a co-morbidity not related to metabolic syndrome the study was excluded. Studies were included regardless of language. Any retrieved studies not in English were translated using Google Translate. Animal and *in vitro* studies were excluded. Reviews were excluded.

2.3. Study selection and data collection

The articles identified from title and abstract screening were added into a Microsoft Excel spreadsheet, the papers retrieved, and final inclusion decisions made by reading the full text. Two reviewers (MM and VR) screened this list to decide on the final included studies. For each article, the following data were entered into the spreadsheet: study type, herb/spice investigated, population, dose of herb/spice, length of study and outcome measures. The evidence for each herb/spice was clustered into type of metabolic health measurement investigated, and whether there were positive findings or not. The Jadad Scale was used to score the methodological quality of the clinical trials. The Jadad scale was originally developed for assessing clinical trials in pain research, but has been widely adapted and is considered to offer the best validity and reliability evidence [26]. One point is scored for each of the following: a mention of randomization; description of an appropriate randomization method; mention of blinding; description of appropriate blinding method; and, all participants in the trial being accounted for in the results. Trials that scored 0 – 2 were considered low quality and those scoring 3 – 5 were considered high quality.

3. Results

The PubMed search identified 792 results while the Scopus search produced 925 results. An additional 25 papers were found from Google Scholar and reference list scanning. Title and abstract screening led to 258 papers for full text screening. This led to a total of 146 relevant papers for data extraction (Figure 1).

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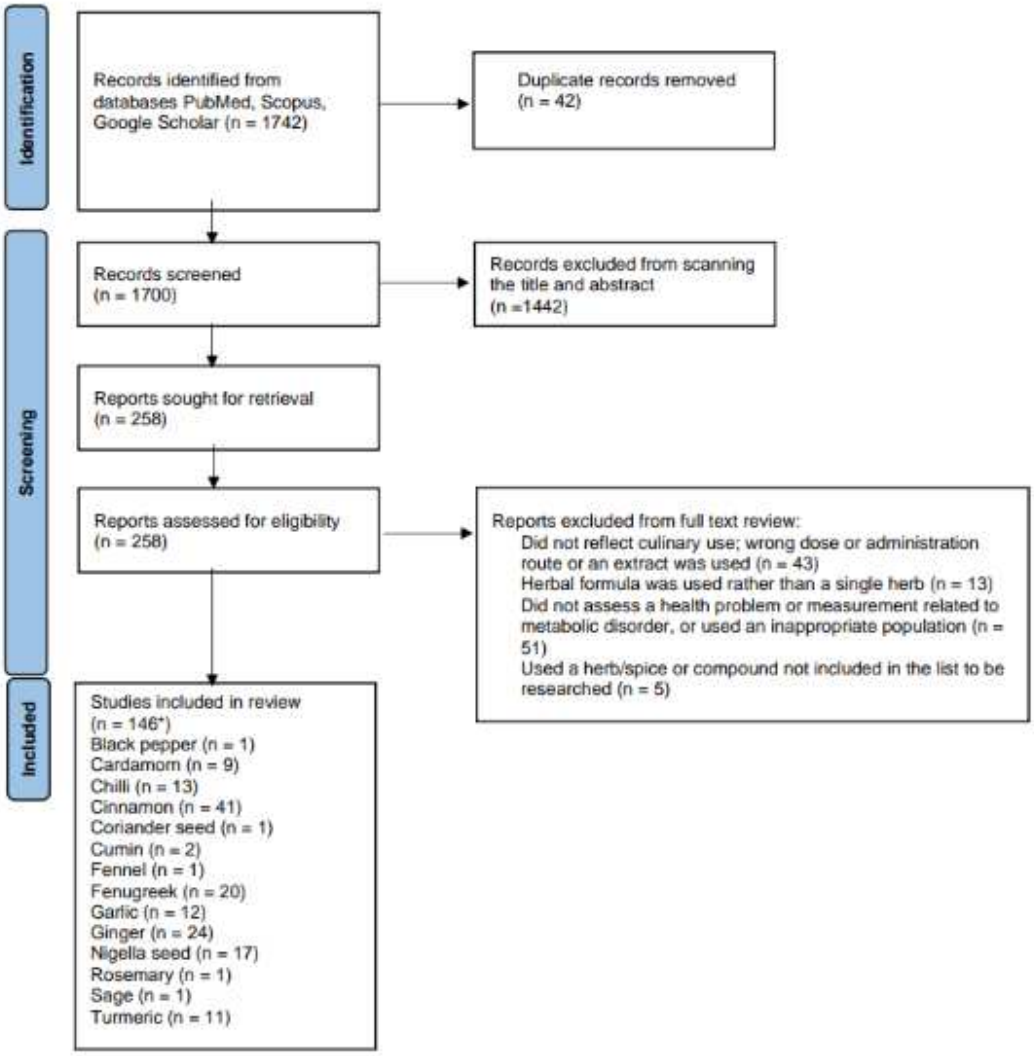

Figure 1. PRISMA flow diagram of the screening process. *The number of studies for all the individual herbs has a total sum of more than 145, as some studies included more than one herb in each arm of the study.

Evidence was found for black pepper, chilli, cardamom, cinnamon, cloves, coriander, cumin, fennel, fenugreek, garlic, ginger, Nigella seed, rosemary, sage and turmeric. No relevant research was found for mint, oregano, parsley or thyme. Table 1 summarises the included studies. The rationale behind studies excluded at full text screen is shown in Supplementary Table 1.

Table 1. Summary of results from included studies.

Herb or spice	Reference	Study type	Population	Dose and formulation	Length of intervention	Findings	Study Quality
Cardamom	28	Single-blind clinical trial	20 individuals with hypertension	3g/day in capsules	12 weeks	BP significantly decreased and fibrinolytic activity increased. Fibrinogen and lipid levels did not change.	Low
	32	Double-blind RCT	80 prediabetic subjects	3g/day in capsules	8 weeks	Inflammatory markers CRP, CRP:IL-6 ratio and oxidative stress marker MDA were all decreased significantly	High

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	29	Double-blind RCT	83 overweight or obese diabetic patients	3g/day in capsules	10 weeks	There was an improvement in HbA1c, insulin control and TG and an increase in Sirt1. Cholesterol levels did not change.	High
	36	Double-blind RCT	87 overweight or obese patients with NAFLD	3g/day in capsules	12 weeks	Cardamom improved fatty liver grade, blood glucose, lipids and irisin, but BMI, total cholesterol and FBG were not changed.	High
	37	Double-blind RCT	83 pts with type 2 diabetes	3g/day in capsules	10 weeks	Cardamom led to a sig decrease in CRP and systolic BP, and an increase in serum NO. Serum ADMA and diastolic BP did not change.	High
	31	Double-blind RCT	83 overweight pts with type 2 diabetes	3g/day in capsules	10 weeks	VCAM, ICAM, E-selectin and IL-6 were sig decreased in the cardamom group. MMP-9 and CD163 levels were unchanged.	High
	35	Double-blind RCT	87 pts with NAFLD	3g/day in capsules	12 weeks	Cardamom sig increased Sirt1 and decreased inflammatory markers hs-CRP, IL-6, TNFα and liver marker ALT, as well as improving the degree of fatty liver. Weight, BMI and AST did not change.	High
	34	Double-blind RCT	194 obese women with PCOS	3g/day in capsules	16 weeks	Anthropometric indices decreased. Glycemic indices and androgen hormones improved.	High
	33	Double-blind RCT	194 obese women with PCOS	3g/day in capsules	16 weeks	LH, androstenedione and dehydroepiandrosterone were decreased. FSH increased. Inflammatory markers TNFα, IL-6 and CRP were decreased	High
	42	Cross-over clinical trial	7 healthy volunteers	30g fresh chilli	Single dose	A combination of chilli and medium-chain TG sig increased diet-induced thermogenesis	Low
Chilli	38	Randomized cross-over study	36 healthy participants	30g/day chilli in food	8 weeks	When participants with a BMI >26 consumed a chilli-containing meal after 4 weeks of daily chilli, there was reduced C-peptide and insulin and higher hepatic clearance of insulin. But blood glucose and energy expended were not sig changed.	High
	39	Randomized cross-over study	27 healthy adults	30g/day chilli in food	8 weeks	Consumption of chilli increased the resistance of lipoproteins to oxidation, but had no effect on serum lipids, lipoproteins and total antioxidant score.	Low

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40	Randomized cross-over study	36 healthy participants	30g/day chilli in food	8 weeks	There were no effects on metabolic or vascular parameters (glucose, lipids, BP, insulin). However, in men, chilli decreased resting heart rate and increased myocardial perfusion time.	High
9	Randomized cross-over study	34 healthy overweight volunteers	Meal containing chilli with 5.82mg total capsaicinoids	Single dose	Chilli decreased post-prandial insulin when added to a meal. Metabolic rate, core temperature, CRP and microvascular reactivity were unchanged.	Low
46	Cross-over clinical trial	40 healthy adults	0.6g in food	Single dose	Eating a meal with chilli in increased the desire to eat sweet food, but had no impact on energy intake	Low
45	Randomized cross-over study	12 healthy adults	10mg capsaicinoids/day in capsules	5 weeks	There was no change in anthropometric and metabolic measurements from chilli consumption. Chilli increased the firmicutes/bacteroidetes ratio and faecalibacterium abundance that coincided with the increase of plasma levels of GLP-1 and GIP and the decrease of plasma ghrelin level. Benefits were linked to gut enterotypes.	Low
47	Double-blind RCT	42 pregnant women with gestational diabetes	1.25g/day added to food	4 weeks	Postprandial glucose, insulin and insulin resistance were sig reduced by chilli. Serum cholesterol and triglyceride were also reduced by chilli. Serum calcitonin gene-related peptide was sig increased by chilli. When the babies were born, chilli had sig reduced the incidence of large-for-gestational age newborns.	High
49	Prospective cohort study	12970 healthy adults	<20g/day up to >50g/day in food	9 years	Chilli intake was inversely associated with risk of hypertension in Chinese adults	
48	Prospective cohort study	12970 healthy adults	<20g/day up to >50g/day in food	9 years	There was a positive association between chilli intake and energy intake, however, chilli consumption was inversely associated with incidence of overweight/obesity	
41	Cross-over clinical trial	12 healthy adults	5g in capsules	Single dose	When 5g of chilli was administered in a capsule after a glucose challenge, plasma glucose levels were sig lower after 30 and 45 mins	Low

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						than those in the placebo group. Insulin levels in the chilli group were sig higher than in the placebo group at 1 and 2 hours after glucose challenge.	
	43	Single-blind, randomized, cross-over trial	14 healthy volunteers	3.09g/day in food	36 hours	Chilli increased fat oxidation and prevented reductions in sleeping metabolic rate, diet-induced thermogenesis or resting energy expenditure that were caused by restricting food intake. This indicates a potential beneficial effect in dieting individuals. There was no effect of chilli on BP	Low
	44	Single-blinded, randomized, cross-over design	15 healthy adults	3.09g/day in food	36 hours	Chilli significantly decreased the desire to eat and increased satiety and fullness, particularly when participants under-ate.	Low
	59	Single-blind randomized cross-over study	8 sedentary, healthy males	3g/day in capsules	2 weeks	Cinnamon reduced glucose response to a glucose challenge and improved insulin sensitivity, but effects were not long-lasting once cinnamon consumption ceases.	High
	74	Double-blind RCT	25 post-menopausal women with type 2 diabetes	1.5g/day in capsules	7 weeks	Cinnamon did not improve fasting plasma glucose or insulin concentrations, whole-body oral glucose tolerance, or blood lipid profiles	Low
	58	Randomized cross-over study	7 lean, healthy adults	5g in capsules	Single dose	Cinnamon reduced plasma glucose responses to glucose tolerance tests and improved insulin sensitivity	Low
Cinnamon	53	Randomized cross-over study	15 healthy adults	1 or 3g/day in food	Single dose	Ingestion of 3 g cinnamon reduced postprandial serum insulin and increased GLP-1 concentrations without significantly affecting blood glucose, GIP, the ghrelin concentration, satiety, or GER in healthy subjects. 1g did not have an effect	High
	55	Single-blind randomized cross-over study	9 healthy young adults	3g in capsules	Single dose	3 g cinnamon did not alter the postprandial response to a high-fat test meal. No change in gastric emptying, glucose response, arterial function, oxidative stress or appetite.	High
	87	Double-blind cross-over RCT	10 individuals with impaired glucose tolerance	6g in capsules	Single dose	No sig differences in glucose or insulin responses compared with placebo	High

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88	Double-blind cross-over RCT	10 young, sedentary obese women	5g in capsules	Single dose	Peak blood glucose was lower in the cinnamon group, but blood insulin and insulin sensitivity/resistance were not affected.	High
71	Double-blind RCT	26 pts with type 2 diabetes	1g/day in capsules	12 weeks	Cinnamon sig reduced FBG by 6 weeks that this was maintained for the whole 12 weeks of the study. The decrease in HbA1c was not significant. Serum glutathione and superoxide dismutase were sig increased by cinnamon at 12 weeks, while MDA was sig reduced, indicating an overall antioxidant effect.	Low
54	Randomized cross-over study	30 healthy obese or normal weight individuals	6g powder in food	Single dose	Cinnamon sig reduced blood glucose in obese and healthy weight individuals	Low
51	Randomized clinical trial	30 healthy adults	100ml cinnamon tea	Single dose	Cinnamon sig decreased postprandial maximal glucose level	Low
52	Crossover clinical study	14 healthy individuals	6g powder in food	Single dose	Cinnamon sig reduced the postprandial glucose response and the gastric emptying rate.	Low
50	Randomized crossover study	10 healthy individuals	6g in food	Single dose	Cassia cinnamon, but not Ceylon cinnamon, reduced postprandial insulin and glucose responses	Low
83	Double-blind RCT	45 women with PCOS	1.5g/day in capsules	24 weeks	Menstrual cyclicity improved for women taking cinnamon with no effect on insulin resistance or serum androgens	High
64	Single-blind RCT	109 adults with diabetes	1g/day in capsules	12 weeks	Cinnamon lowered HbA1c	High
72	Single-blind RCT	60 patients with type 2 diabetes	1.5g/day	12 weeks	Cinnamon had no impact on fasting plasma glucose, HbA1c, or serum lipids	
63	Double-blind RCT	43 individuals with diabetes	1g/day in capsules	12 weeks	Cinnamon produced no significant change in fasting glucose, lipid, A1C, or insulin levels	High
86	Double-blind RCT	50 pts with NAFLD	1.5g/day in capsules	12 weeks	significant decreases in HOMA index, fasting blood glucose, total cholesterol, triglyceride, ALT, AST, GGT, and high-sensitivity CRP with cinnamon	High
73	Double-blind RCT	39 adults with diabetes	3g/day in capsules	8 weeks	Cinnamon had no effect on glycaemic and inflammatory markers	High
69	Double-blind RCT	44 adults with diabetes	3g/day in capsules	8 weeks	Cinnamon had no effect on soluble vascular adhesion molecules	High

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84	Single-blind RCT	40 women with PCOS	1.5g of Ceylon cinnamon in capsules	8 weeks	Sig improvement in cyclicity with cinnamon, which was equivalent to metformin. No change in fasting blood glucose or serum progesterone or androgen levels.	High
65	Double-blind RCT	39 adults with diabetes	3g/day in capsules	8 weeks	Cinnamon had no effect on inflammatory markers	High
61	Double-blind RCT	57 adolescents with diabetes	1g/day in capsules	12 weeks	Cinnamon had no effect on A1c or insulin sensitivity	High
60	Double-blind RCT	58 patients with type 2 diabetes	2g/day in capsules	12 weeks	Intake of 2g of cinnamon significantly reduced the HbA1c, SBP and DBP among poorly controlled type 2 diabetes patients	High
75	Double-blind RCT	59 adults with type 2 diabetes	1.2g/day in capsules	12 weeks	There was no significant change in SBP from baseline when cinnamon was compared with placebo	High
76	Double-blind RCT	136 individuals with type 2 diabetes	1.5g/day in capsules	90 days	HbA1c was sig reduced by cinnamon, but there was no effect on FBG.	High
77	Double-blind RCT	61 pts with type 2 diabetes	2g/day in capsules	8 weeks	Cinnamon did not sig improve FBG, HbA1c, blood lipids	High
79	Double-blind RCT	84 overweight individuals with PCOS	1.5g/day in capsules	8 weeks	Cinnamon increased serum antioxidant capacity, and improved total cholesterol, LDL and HDL	High
80	Double-blind RCT	84 overweight individuals with PCOS	1.5g in capsules	8 weeks	Cinnamon significantly decreased serum FBG, insulin, homeostatic model assessment for insulin resistance, total cholesterol and LDL-cholesterol and weight and increased HDL-cholesterol compared with placebo	High
68	Triple-blinde RCT	105 pts with type 2 diabetes	1g/day in capsules	12 weeks	Cinnamon sig improved glucose control and reduced BMI	High
70	Double-blind RCT	115 pts with type 2 diabetes	0.5g/day in capsules	12 weeks	Cinnamon sig reduced FBG, HbA1c and hepatic enzymes. Probiotics were also effective.	High
66	Double-blind RCT	60 people with type 2 diabetes	1, 3, or 6g/day in capsules	40 days	Intake of 1, 3, or 6g of cinnamon per day reduces serum glucose, triglyceride, LDL-cholesterol, and total cholesterol inpeople with type 2 diabetes	High
85	Double-blind RCT	116 Asian Indians with metabolic syndrome	3g/day	16 weeks	FBG, HbA1c, waist circumference, and BMI were significantly reduced by cinnamon. Waist-hip ratio, BP, serum total cholesterol, LDL-cholesterol, serum triglycerides, and HDL-	High

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						cholesterol were also sig improved.	
	67	Triple-blind RCT	160 people with type 2 diabetes	3g/day	12 weeks	Cinnamon reduced HbA1c and blood glucose	High
	78	Triple-blind RCT	140 patients with diabetes	1g/day	12 weeks	Cinnamon supplementation led to improvement of all anthropometric (BMI, body fat, and visceral fat), glycemic (FBG, 2hpp, HbA1C, fasting insulin, and insulin resistance), and lipids (cholesterol, LDL-c and HDL-c) outcomes (except for triglycerides)	High
	82	Double-blind RCT	59 women with PCOS	1.5g/day	12 weeks	fasting insulin, HOMA-IR, LDL and HDL were sig reduced in the cinnamon group. Changes in blood sugar, serum androgen levels and anthropometric measures were not significant.	High
	57	Open, randomized, cross-over clinical trial	21 healthy volunteers	2g in 200ml hot water	Single dose	No sig difference in energy expenditure, dietary-induced thermogenesis, hunger fullness and desire to eat. However, cinnamon tea decreased satiety and increased food intake in the subsequent meal.	Low
	56	Randomized cross-over study	18 healthy adults	4g	Single dose	Cinnamon decreased blood glucose and satiety 15 min after test meal, but didn't decrease blood sugar overall.	Low
Cinnamon and ginger	81	Double-blind RCT	83 women with PCOS	1.5g of cinnamon or ginger	8 weeks	Cinnamon and ginger both sig decreased weight and BMI. Insulin resistance decreased, but only in the cinnamon group. FSH and LH sig decreased in the ginger group, while testosterone was sig reduced in the cinnamon group.	High
Cinnamon, cardamom, saffron, ginger	62	Single-blind RCT	208 pts with type 2 diabetes	3g	8 weeks	No significant difference in BP, serum soluble (s)ICAM-1 concentrations and anthropometric measures	High
Cumin	92	Randomized clinical trial	88 overweight/obese women	6g/day	12 weeks	Cumin powder reduced serum levels of fasting cholesterol, triglyceride, and LDL and increased HDL. Weight, BMI, waist circumference, fat mass and its percentage significantly reduced	High

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Cumin and cinnamon	89	Double-blind RCT	99 women with dyslipidemia	3g/day	8 weeks	Cumin and cinnamon both sig reduced total cholesterol compared with placebo. Differences in triglycerides, HDL and LDL were not significant.	High
Fennel and fenugreek	93	Single-blinded cross-over trial	9 healthy women	2g fennel infused in 250ml of water and strained. 24g of fenugreek, infused in 250ml of water and strained.	Single dose (with 1-week washout between each arm of the study)	Both fennel and fenugreek increased feelings of fullness and decreased desire to eat food, however, there were no changes in amount of food consumed after drinking either tea compared with placebo tea.	Low
Fenugreek	112	Clinical trial	20 adults with hypercholesterolemia	12.5-18g/day	4 weeks	Total cholesterol and LDL cholesterol sig decreased at both doses.	Low
	108	Clinical trial	pts with type 1 diabetes	100g/day	10 days	Fenugreek sig reduced fasting blood sugar, improved glucose tolerance, and reduced LDL, total cholesterol and triglycerides	
	104	Clinical trial	Type 2 diabetics	15g	Single dose	Postprandial glucose was sig decreased, but there was no impact on insulin or lipids	
	95	Double-blind RCT	13 healthy volunteers	3g/day	10 days	Fenugreek improved glucose tolerance and insulin sensitivity (as shown by reduction in melanin-concentrating hormone)	High
	94	Double-blind cross-over RCT	10 healthy volunteers and 6 pts with type 2 diabetes	Bread with 10% fenugreek	Single dose	Adding fenugreek (1 part to 9 parts of wheat flour) reduced the glycaemic response and GI of bread in both healthy volunteers and diabetics	Low
	102	Clinical trial	18 pts with type 2 diabetes	10g/day	8 weeks	FBS, TG and VLDL-C decreased significantly (25 %, 30 % and 30.6 % respectively) after taking fenugreek seed soaked in hot water whereas there were no significantly changes in lab parameters in cases who consumed it mixed with yoghurt	Low
	103	Double-blind RCT	8 pts with diabetes	5.6g in bread	Single dose	Blood glucose was not changed, but total insulin concentration decreased	High
	96	Randomized cross-over study	10 healthy adults	Bread with 10% fenugreek	Single dose	Adding fenugreek reduced the glycaemic response and GI of bread	Low
	105	Randomized clinical trial	12 pts with uncontrolled diabetes	2g/day	12 weeks	Blood glucose was not changed, but fasting insulin level increased significantly. The ratio of HDL:LDL sig decreased	Low

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	110	Parallel randomized study	48 pts with type 2 diabetes	15g/day fenugreek powder	8 weeks	Fenugreek sig decreased CRP and increased superoxide dismutase. There was no effect on glutathione peroxidase activity, total antioxidant capacity, IL-6 or TNFα	High
	109	Clinical trial	60 type 2 diabetics	25g/day	24 weeks	Serum cholesterol and triglyceride were sig reduced	Low
	97	Cross-sectional observational study	25 patients with type 2 diabetes	5g/day	12 weeks	Fasting blood glucose was decreased significantly by month 2. Postprandial blood glucose level was sig lower by month 3.	
	99	Parallel randomized study	50 pts with type 2 diabetes	15g/day fenugreek powder	8 weeks	Fenugreek sig decreased fasting blood glucose, and liver enzymes, serum ALT and alkaline phosphatase, compared with baseline. Compared with control group, SBP, AST and irisin (a marker of metabolic health) were decreased.	High
	98	RCT	114 pts with type 2 diabetes	50g/day	4 weeks	Fenugreek improved lipid metabolism	Low
	113	Double-blind RCT	56 adults with borderline hyperlipidemia	8g/day	8 weeks	TG, LDL, total cholesterol and FBG were sig decreased by fenugreek	High
	106	Triple-blind RCT	88 pts with type 2 diabetes	10g/day	8 weeks	Fenugreek seeds significantly decreased FBG and HbA1c, serum levels of insulin, HOMA-IR, total cholesterol and TG and increased serum levels of adiponectin	High
	100	Double-blind RCT	125 pts with type 2 diabetes	10g/day	8 weeks	Fenugreek alone and fenugreek combined with nutrition training sig decreased FBG, HbA1c, BMI and waist circumference compared with placebo.	High
	101	Double-blind RCT	62 pts with type 2 diabetes	10g/day fenugreek powder	8 weeks	Fenugreek sig improved mean FBG, HgA1C, BMI, waist circumference, DBP, and quality of life	High
	107	Randomized cross-over study	8 healthy individuals	25g	single dose	Fenugreek seeds sig reduced the rise in blood glucose and insulin caused by a meal.	Low
Garlic	117	Clinical trial	40 patients with metabolic syndrome	100mg/kg bodyweight crushed garlic	4 weeks	Raw crushed garlic significantly reduced waist circumference, SBP and DBP, TG, FBG and significantly increased serum HDL cholesterol. There was no significant difference found in BMI	Low
	120	Clinical trial	4 healthy adults	40g fresh garlic	1 week	Garlic sig reduced the serum cholesterol and triglycerides	Low

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						when consumed with a high-fat diet	
	121	Clinical trial	20 healthy individuals	3g/day	90 days	Garlic sig reduced total cholesterol and LDL, but had no impact on toal bacterial faecal count	
	119	Single-blind randomized cross-over study	18 healthy volunteers	4.2g	1 week	Baseline values of platelet function were within normal range in all volunteers. Platelet function was not impaired by single and repeated oral consumption of Greek tsatsiki containing raw garlic	Low
	116	Randomized clinical trial	112 hyperlipidemic patients	20g/day	8 weeks	Garlic and a combination of garlic and lemon sig reduced blood lipids (total cholesterol, TG and LDL) and BP, while increasing HDL.	Low
	114	Retrospective cohort study	101 healthy adults			There was a significant association between people who eat higher levels of garlic in the diet and those with lower SBP. 232g garlic/month = <100mmHg vs 148g garlic/month = >120mmHg	
	118	Double-blind RCT	90 overweight smokers	2.1g/day	12 weeks	Garlic had no significant effect on inflammatory biomarkers, endothelial function, or lipid profile in normolipidemic subjects with risk factors for CVD	High
	125	Double-blind RCT	90 pts with NAFLD	1.6g/day	12 weeks	Garlic decreased hepatic steatosis, liver enzymes and blood lipids (total cholesterol, TG, HDL and LDL)	High
	124	Double-blind RCT	90 pts with NAFLD	1.6g/day	12 weeks	Waist circumference, body fat, FBG, insulin and insulin resistance sig improved. Skeletal muscle mass increased and antioxidant capacity increased.	High
	123	Double-blind RCT	90 pts with metabolic syndrome	1.6g/day	12 weeks	Garlic increased HDL. Sig decreases in waist circumference, BP, TG, insulin and appetite.	High
	115	Cross-sectional cohort study	22812 adults	Raw garlic		There was an inverse association between higher garlic intake and prehypertension	
Garlic and coriander seed	91	Single-blind RCT	80 pts with hyperlipidemia	2g/day	40 days	Garlic and coriander improved BMI, total cholesterol, HDL and LDL. Garlic powder was more effective than coriander	Low
Ginger	143	Double-blind RCT	160 obese children with NAFLD	1g/day	12 weeks	Serum FBG and CRP, BMI, waist circumference, AST, hepatic steatosis, total	High

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					cholesterol and LDL sig decreased with ginger.	
127	Placebo-controlled study	23 healthy male volunteers	1g	Single dose	Ginger had no effect on thermoregulatory function, but increased fat utilisation in the morning	High
126	Randomized cross-over study	18 healthy volunteers	15g raw ginger or 40g cooked ginger	2 weeks	Ginger did not affect thromboxane production	High
128	Randomised cross-over study	10 healthy men	2 g	2 days	Ginger significantly enhanced thermogenesis and reduced hunger and food intake.	Low
139	Double-blind RCT	20 60-year-old patients with diabetes	3 g	12 weeks	Significant improvements found in blood glucose, insulin resistance, inflammatory and oxidative markers (CRP and MDA).	High
140	Double-blind RCT	45 diabetic patients	2g/day	10 weeks	Ginger supplementation decreased ADMA serum levels (although this change wasn't sig different to placebo), but had no effect on sICAM-1.	High
144	Double-blind RCT	50 pts with NAFLD	1.5g/day of ginger	12 weeks	No sig difference between ginger and placebo for anthropometric measurements or liver markers. However, FBG and insulin resistance were sig improved by ginger. Serum lipids (total cholesterol and LDL) and CRP sig decreased in the ginger group.	High
141	Double-blind RCT	45 diabetic patients	2g/day	10 weeks	No effect of ginger on anthropometric measurements or NFκB	High
135	Double-blind RCT	64 pts with type 2 diabetes	2g/day	8 weeks	TNFα and hs-CRP were sig reduced by ginger. IL-6 was reduced by ginger compared with baseline, but not sig compared with placebo	High
134	Double-blind RCT	64 pts with diabetes	2g/day	8 weeks	Ginger supplementation significantly lowered the levels of insulin, LDL-cholesterol, TG and the HOMA index and increased the QUICKI index, but had no effect on FBG, total cholesterol, HDL-C and HbA1c.	High
138	Double-blind RCT	88 diabetics	3g/day	8 weeks	Ginger improved fasting blood glucose, insulin levels and insulin sensitivity	High
129	Double-blind RCT	80 healthy obese women	2g/day	12 weeks	Ginger decreased anthropometric measurements and appetite	High

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137	Double-blind RCT	70 women with gestational diabetes	1.5g/day	6 weeks	Ginger treatment significantly reduced the levels of FBS, serum insulin and HOMA index, but did not affect postprandial blood sugar	High
131	Double-blind RCT	70 Obese women	2g/day	12 weeks	Ginger sig reduced blood glucose, total cholesterol, TG and LDL/HDL, while increasing MDA and HDL. Body weight, waist circumference and BMI were also sig reduced without any difference in energy and macronutrient intake between groups.	High
145	Pilot double-blind RCT	60 hypothyroid patients with normal serum TSH	1g/day	30 days	Ginger sig reduced the thyroid symptom score. Additionally, weight gain, cold intolerance, constipation, dry skin, appetite, memory loss, concentration disturbance, and feeling giddy or dizzy domains also sig improved. Ginger supplementation also led to a significant decrease in body weight, BMI, waist circumference, serum TSH, FBG, TG, and total cholesterol levels compared to the placebo.	High
136	Double-blind RCT	70 pts with type 2 diabetes	1.6 g	12 weeks	Ginger sig reduced multiple markers of metabolic health (blood glucose, insulin, insulin resistance, cholesterol) and inflammation (CRP and prostaglandin).	High
130	Double-blind RCT	80 Obese women	2g	12 weeks	Statistically significant reduction in BMI, serum insulin and HOMA-IR.	High
132	Double-blind RCT	103 pts with diabetes	1.2g/day	12 weeks	Ginger sig reduced fasting blood glucose and total cholesterol	High
133	Double-blind RCT	41 pts with type 2 diabetes	2g/day	12 weeks	Ginger supplementation significantly reduced the levels of fasting blood sugar, HbA1c, apolipoprotein B, apolipoprotein B/apolipoprotein A-I and MDA in ginger group in comparison to baseline, as well as control group, while it increased the level of apolipoprotein A-I	High
142	Double-blind RCT	85 pts with hyperlipidemia	3g/day	45 days	TG and cholesterol levels were sig lower in the ginger group than placebo. Changes in LDL and HDL were not	High

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						significant between the two groups	
Ginger and fenugreek	111	Placebo-controlled study	30 patients with coronary artery disease and 30 healthy individuals	4g/day or 10g one-off dose of ginger. 5g/day fenugreek	12 weeks	Ginger did not affect platelet aggregation when given at 4g/day, but 10g single dose reduced platelet aggregation. Ginger had no effect on blood sugar or blood lipids. Fenugreek had no effect on cholesterol, TG or blood sugar in healthy individuals, but reduced cholesterol and triglycerides in pts with coronary artery disease and diabetes	Low
Mustard, black pepper, ginger, horseradish	27	Single-blind cross-over trial	22 young, healthy males	20g ginger or 1.3g of black pepper	Single dose	Ginger and black pepper had no effect on appetite, energy intake or diet-induced thermogenesis	High
Nigella seeds	153	Double-blind cross-over RCT	51 pts with metabolic syndrome	3g/day	8 weeks	Nigella had no sig effect on BP, weight, waist circumference, FBG and BMI	High
	152	Double-blind cross-over RCT	51 pts with metabolic syndrome	3g/day	8 weeks	No sig effect of Nigella on blood lipids, apolipoproteins and inflammatory factor	High
	146	Double-blind RCT	30 healthy male volunteers	1g/day	4 weeks	Nigella seeds had no effect on glycaemia or insulin. Total cholesterol and LDL-cholesterol were decreased with no effect on triglycerides or HDL-cholesterol.	Low
	160	Clinical trial	94 pts with type 2 diabetes	1, 2 or 3g/day	12 weeks	Sig reductions in FBG, postprandial glucose, HbA1c and insulin resistance from 2g/day. No effect on serum C-peptide or body weight.	Low
	151	Placebo-controlled study	35 menopausal women with metabolic syndrome	1g/day	8 weeks	No sig change in body weight. Nigella sig reduced FBG. Total cholesterol, TG and LDL were sig reduced. HDL change wasn't sig.	Low
	155	Randomized controlled trial	37 menopausal women with moderate risk of hyperlipidemia	1g/day	8 weeks	Sig decrease in hyperlipidemia from Nigella	Low
	158	Single-blind, non-randomized trial	114 pts with type 2 diabetes	2g/day	one year	N sativa group had a significant decline in TC, LDL-cholesterol, total cholesterol/HDL-C and LDL/HDL ratios, as well as DBP, mean arterial pressure and heart rate.	High
	156	Double-blind RCT	73 adults with hyperlipidemia	2g/day	6 weeks	No significant effects were seen for blood sugar or lipids	High

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	149	Double-blind RCT	40 pts with Hashimoto's thyroiditis	2g/day	8 weeks	Nigella sativa supplementation significantly reduced anthropometric variables including weight, BMI, and waist circumference. Serum TSH and anti-TPO concentrations reduced while serum T3 increased in Nigella sativa treated group. VEGF also decreased significantly in Nigella group.	High
	161	Double-blind RCT	50 pts with NAFLD	2g/day	12 weeks	Levels of CRP and NFκB were sig decreased by Nigella. No sig change in hepatic steatosis or TNFα.	High
	162	Double-blind RCT	50 pts with NAFLD	2g/day	12 weeks	Sig reduction in glucose, insulin and insulin resistance, but no change to lipid profile. Percentage of hepatic steatosis also decreased	High
	150	Double-blind RCT	40 pts with Hashimoto's thyroiditis	2g/day	8 weeks	Nigella seeds sig decreased TG, LDL, weight and BMI, and increased SOD and total antioxidant capacity.	High
	159	Double-blind RCT	114 pts with type 2 diabetes	2g/day	one year	No change to BMI. Nigella led to a decrease in FBG, HbA1c and insulin resistance	High
	154	Double-blind RCT	140 menopausal women with metabolic syndrome	500mg/day	8 weeks	LDL-cholesterol, TG, total cholesterol and FBG decreased significantly	High
	148	Double-blind RCT	39 men with obesity	3g/day	12 weeks	There was no change in serum free testosterone, FBG, TG and inflammatory markers. However, body weight, waist circumference and BP did improve.	High
	157	Randomized, placebo-controlled trial	74 individuals with hypercholesterolemia	2g/day	4 weeks	Nigella seed sig lowered triglycerides, LDL and cholesterol compared with baseline, but had no effect on blood glucose or HDL.	High
Rosemary	163	Double-blind RCT	110 pts with NAFLD	4g/day	8 weeks	There were no sig effects on liver enzymes, anthropometric measurements, FBG, insulin, insulin resistance and blood lipids from rosemary when compared with placebo.	High
Sage	164	Non-randomized cross-over trial	6 healthy female volunteers	600ml sage tea/day	4 weeks	No effects on blood glucose, but LDL and total cholesterol decreased, while HDL increased. Lymphocyte hsp70 expression also increased	Low
Turmeric	166	Single-blinded RCT	42 women with type 2 diabetes	2.1g/day	8 weeks	There was a sig improvement in body composition, lipid profile and glycemic status in	High

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			and hyperlipidemia			the turmeric group and the aerobic training or the aerobic training plus turmeric groups compared with control group. The combined group also had sig lower blood lipids, blood glucose and insulin than turmeric alone group.	
	170	Randomized cross-over study	14 healthy volunteers	6g	Single dose	Turmeric increased postprandial insulin without affecting plasma glucose	High
	165	Open-label, randomized clinical trial	60 diabetic pts on metformin	2g/day	4 weeks	Turmeric sig reduced fasting plasma glucose, but had no effect on post-prandial glucose. Turmeric also increased glutathione, MDA and CRP compared with baseline. LDL cholesterol was sig decreased compared with baseline.	High
	174	Double-blind RCT	46 pts with NAFLD	3g/day	12 weeks	Turmeric consumption decreased serum levels of glucose, insulin, HOMA-IR and leptin. Changes in weight, BMI and liver enzymes were not significant	High
	167	Randomized, single-blinded placebo-controlled trial	42 hyperlipidemic pts with type 2 diabetes	2.1g/day	8 weeks	Turmeric alone and turmeric plus aerobic training sig decreased waist circumference, FBG, TG and BP, while HDL cholesterol increased. Metabolic syndrome Z score and inflammatory markers significantly improved in both turmeric groups.	High
	168	Double-blind RCT	80 type 2 diabetes mellitus patients (30-70 years old)	2.1g turmeric powder	8 weeks	Turmeric was found to significantly decrease body weight, TG and total cholesterol.	High
	173	Double-blind RCT	64 pts with NAFLD	2g/day	8 weeks	Turmeric sig reduced liver enzymes AST, ALT and GGT compared with placebo. Triglycerides, LDL, HDL and MDA sig decreased from baseline, but weren't sig different from placebo.	High
	169	Double-blind RCT	114 pts with type 2 diabetes	1.2g/day	12 weeks	Turmeric sig reduced arterial stiffness. No change was found in markers of endothelial function.	High
Turmeric and Nigella seed	147	Double-blind RCT	250 healthy men with metabolic syndrome	1.5g/day Nigella, 2.4g/day turmeric	8 weeks	Nigella seed led to sig improvement in triglycerides, total cholesterol, LDL and HDL, but no change to anthropometric measures, blood glucose, BP or inflammation. Turmeric sig	High

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						improved cholesterol, LDL and inflammation, but not TG, HDL, anthropometric measures, BP or blood glucose.	
Turmeric and cinnamon	90	Double-blind RCT	48 people >60 years with prediabetes	1g turmeric or 2g of cinnamon	Single dose	Co-ingestion of turmeric with white bread increases working memory independent of body fatness, glycaemia, insulin, or AD biomarkers. Cinnamon had no impact on working memory. Use of turmeric or cinnamon regularly had no impact on glycaemia or insulin responses to breakfast	High
Turmeric and red pepper spice	171	Double-blind cross-over RCT	98 overweight or obese women	2.8g turmeric/ day	4 weeks	Turmeric does not alter oxidative stress or inflammation in overweight/obese females with systemic inflammation, or cause a significant shift in the global metabolic profile	High

AD: Alzheimer's disease, ADMA: asymmetric dimethylarginine, ALT: alanine transaminase, AST: aspartate aminotransferase, BMI: body mass index, BP: blood pressure, CRP: c-reactive protein, CVD: cardiovascular disease, DBP: diastolic blood pressure, FBG: fasting blood glucose, FSH: follicle stimulating hormone, GER: gastric emptying rate, GGT: γ-glutamine transpeptidase, GI: glycaemic index, GIP: glucose-dependent insulinotropic polypeptide, GLP: glucagon-like peptide, HbA1c: glycated haemoglobin, HDL: high-density lipoprotein, HOMA-IR: homeostasis model assessment of insulin resistance, 2hpp: 2-hour postprandial, hsp: heat shock protein, IL: interleukin, LDL: low-density lipoprotein, LH: leutenising hormone, MDA: malondialdehyde, MMP: matrix metalloproteinase, NAFLD: non-alcoholic fatty liver disease, NFκB: nuclear factor κB, NO: nitric oxide, PCOS: polycystic ovarian syndrome, pt: patient, QUICKi index: quantitative insulin sensitivity check index, RCT: randomised-controlled trial, SBP: systolic blood pressure, sICAM: soluble intercellular adhesion molecule, Sirt: sirtuin, SOD: superoxide dismutase, TG: triglycerides, TNF: tumor necrosis factor, TPO: thyroid peroxidase, TSH: thyroid-stimulating hormone, VCAM: vascular cell adhesion protein, VEGF: vascular endothelial growth factor.

3.1. Black pepper

There was one single-blind cross-over trial on black pepper in healthy adults. A dose of 1.3g added to a meal had no impact on appetite or thermogenesis [27].

3.2. Cardamom

Ten studies (9 double-blind RCTs and one clinical study) looked at the impact of cardamom on inflammation and a range of metabolic markers in individuals with hypertension [28], diabetes [29-31], prediabetes [32], poly-cystic ovarian syndrome (PCOS) [33, 34] and non-alcoholic fatty liver disease (NAFLD) [35, 36]. All the studies on cardamom used 3g/day for between 8 and 20 weeks. Five out of six studies that investigated inflammatory markers found positive effects [31-34, 36, 37], two studies found benefits on blood glucose and insulin, two studies found no benefit from cardamom on blood lipids, while effects on blood pressure were variable.

There were more trials with positive findings than an absence of effect in the three main metabolic health markers. The strongest research area was inflammatory markers, with five studies finding a beneficial effect and no studies indicating a lack of effect.

3.3. Chilli

Eleven clinical studies [9, 38-47] and two prospective cohort studies [48, 49] investigated the effects of chilli on appetite, vascular function, and blood glucose, insulin and lipids. Apart from one

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study looking at the effect of chilli on glucose and insulin in pregnant women with gestational diabetes [47], all the included studies were in healthy individuals.

Four of the intervention studies used doses of 30g of fresh chilli [38-40, 42], the other seven intervention studies used doses of 0.6g [46], 1.25g [47], 3.09g [43, 44], 5g [41] a meal with chilli containing 5.82mg of capsaicinoids [9] or chilli capsules containing 10mg of capsaicinoids [45].

Appetite and/or thermogenesis or metabolic rate were measured in eight out of thirteen of the studies and five of these found a beneficial effect. There were as many studies finding positive results as those showing no effect for the key metabolic biomarkers of blood glucose, insulin and lipids (see Figure 2).

One cross-over study found an improvement in diet-induced thermogenesis [42] one single-blind cross-over study found increased metabolic rate [43] and one single-blind cross-over study found decreased appetite from chilli [44], however, four studies found no effect on metabolic rate or energy intake [9, 40, 45, 46]. Chilli was associated with increased energy intake, but lower incidence of being overweight/obese in one prospective cohort study [48]. A second cohort study found an inverse relationship between chilli consumption and hypertension [49]. Reduction in insulin was found in three studies [9, 39, 47], while an increase was found in one [41]. There was no change in blood glucose levels from two randomized cross-over studies [38, 40], while one double-blind RCT [47] and one clinical study [41] found significant reduction in glucose from chilli consumption. The quality of the clinical studies was generally low [8 low and 3 high according to Jadad scores], mainly due to the difficulty in blinding consumption of chilli in food.

3.4. Cinnamon

There were 41 studies looking at the benefits of culinary doses of cinnamon. Ten in healthy individuals [50-59], nineteen in those with diabetes [60-78], six in women with PCOS [79-84], one in Asian Indians with metabolic syndrome [85], one in patients with NAFLD [86], one in individuals with impaired glucose tolerance [87], one in sedentary women with obesity [88], one in women with dyslipidaemia [89], and one in prediabetic individuals [90]. Doses ranged from 1 to 6g; either as a single dose or daily for between 2 weeks and 6 months. Whether a positive effect was seen or not did not appear to correlate with dosage.

Beneficial effects on glucose were found in 6 randomized cross-over studies, 1 randomized trial and 10 double-blind RCTs from doses of 0.5-6g/day, 100ml of cinnamon tea or single doses of 5-6g of cinnamon [50-52, 54, 56, 58, 59, 66-68, 70, 71, 78, 80, 85, 86, 88], while 7 double-blind RCTs, 3 single-blind RCTs and one randomized cross-over study found no effect from a single dose of 1-6g or 1-1.5g/day [53, 63, 72-74, 76, 77, 82, 84, 87, 90].

Beneficial effects on insulin were found in 4 randomized cross-over studies, 10 double-blind RCTs and 1 single-blind RCT from doses of 1-3g/day or single doses of 3-6g of cinnamon [50, 53, 58-60, 64, 67, 70, 76, 78, 80-82, 85, 86], while 6 double-blind RCTs, 1 single-blind RCT and 1 randomized cross-over study found no effect from doses of 1-1.5g/day or a single dose of 6g [53, 61, 71, 72, 74, 77, 87, 90].

3.5. Coriander seed

One single-blind RCT found that 2g/day of coriander seeds for 40 days improved average body mass index (BMI) from 27.3 to 26.7 and blood lipids (total cholesterol, low-density lipoprotein (LDL) and high-density lipoprotein (HDL)), as well as systolic blood pressure in patients with hyperlipidaemia [91].

3.6:. Cumin

Two clinical studies looked at the benefit of cumin on anthropometric measures, blood insulin and blood lipid levels in overweight adults [92] and women with dyslipidaemia [89]. The randomized clinical trial by Zare et al used a dose of 6g/day for 3 months and this reduced all blood lipid measurements, as well as anthropometric measurements of weight, body mass index (BMI), waist circumference and fat [92], while Pishdad et al used 3g/day for 8 weeks in a double-blind RCT and found a benefit on total cholesterol, but not LDL or HDL cholesterol [89].

3.7. Fennel

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One single-blind crossover study found that a single dose of 2g of fennel as a tea decreased appetite in healthy women, but did not impact food consumption [93].

3.8. Fenugreek

There were twenty studies looking at fenugreek, mainly for its impact on blood glucose, insulin and lipids, in healthy individuals [93- 96], diabetics [97-110], individuals with coronary artery disease [111] and adults with hyperlipidaemia/hypercholesterolaemia [112, 113]. Quantities ranged from 2g up to 100g, with the majority of studies using 10-15g/day. Effects on blood insulin, glucose and lipids were promising, with 11 out of 14 studies showing significant positive effects on blood glucose, 7 out of 8 studies finding significant changes in insulin and 6 out of 8 studies significantly improving blood lipids, regardless of dose used. However, excluding low-quality studies reduced the number of studies indicating a benefit on blood glucose (to 4 out of 5 studies) and blood lipid levels (to 1 out of 2 studies).

3.9. Garlic

There were ten clinical studies (4 double-blind RCTs and 6 single-blind or randomized clinical studies) and two cohort studies looking at the benefits of garlic. The two cohort studies investigated the long-term correlation between garlic intake and hypertension, and both found inverse associations [114, 115]. Both clinical trials that looked at the effect of garlic on blood pressure (BP) found benefit when participants consumed 20g or 100mg/kg bodyweight of fresh garlic daily [116, 117]. Most of the studies investigated the impact of garlic on blood lipids. One clinical study was carried out in overweight smokers [118]. Four clinical studies looked at platelet function [119], cholesterol [120, 121], immunity and cancer markers [122] in healthy individuals. Two studies looked at multiple outcomes in patients with metabolic syndrome [117, 123], one study investigated NAFLD [124] and two studies looked at individuals with hyperlipidaemia [91, 116]. For the interventional studies, doses ranged from 1.6g to 40g, with higher doses of fresh garlic compared with dried garlic powder. All but two of the clinical studies looked at blood lipids and seven out of eight found a benefit. Fresh garlic in doses of 100mg/kg body weight, 20g or 40g/day significantly reduced triglycerides in three studies [116, 117, 120], while two studies found that 1.6g/day of dried garlic reduced triglycerides [123, 125]. Total cholesterol was significantly reduced by 1.6, 2 or 3g/day dried garlic and 20g or 40g of fresh garlic [91, 116, 120, 121, 125]. Only one study of overweight participants at risk of cardiovascular disease found no impact of 2.1g of garlic on blood lipids [118].

3.10. Ginger

Out of a total of 24 studies on ginger, six were carried out on healthy individuals to look at blood clotting [126], energy intake and appetite [27], thermoregulatory function or thermogenesis and appetite [127, 128], anthropometric measurements [129, 130], anthropometric measurements and blood glucose and fats [131], and cardiovascular risk factors [111]. There were 11 studies on patients with type 2 diabetes looking at the impact of ginger on blood sugar, insulin and blood lipids [132-134], metabolic health and inflammation [135, 136], fasting blood glucose and insulin sensitivity [137, 138], blood glucose, insulin and inflammation [139], vascular function [140], anthropometric measurements and blood pressure [62], and anthropometric measurements and inflammation [141]. One study looked at the effects of 1.5g of ginger on anthropometric measurements and insulin resistance in women with PCOS [81]. One study looked at the effect of 3g/day on blood lipids in individuals with hyperlipidaemia [142]. Two studies looked at the impact of ginger on liver function, anthropometric measurements, blood sugar and inflammatory markers in individuals with NAFLD [143, 144]. One looked at the impact of 1g of ginger daily in obese children with NAFLD [143], while in the other study, adults were given 1.5g/day [144]. A pilot study investigated the impact of 1g/day of ginger on thyroid symptom score, anthropometric measurements, blood glucose and blood lipids in hypothyroid patients [145].

Ginger was used in doses that ranged from 1g to 10g of dried powdered ginger for a single dose or up to 12 weeks daily; apart from one study that used 15g of fresh ginger or 40g of cooked ginger [126] and another study using 20g of fresh ginger [27]. There did not appear to be a correlation between dose and efficacy. All seven studies that investigated the impact of ginger (doses of 1.5 - 3g/day) on insulin found a benefit, ten out of 12 found positive effects on blood glucose (doses of 1.2

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- 3g/day), six out of seven found a positive effect on blood lipids, such as total cholesterol, LDL and triglycerides (doses of 1 - 3g) and four out of five studies looking at inflammatory markers (doses of 1.5 - 3g) found a benefit. The studies were mainly of high quality (22 out of 24) according to Jadad scoring, with 18 double-blind RCTs, three randomized cross-over studies and three placebo-controlled study.

3.11. Nigella seeds

There were 17 studies on Nigella seeds, mainly investigating their effect on anthropometric measurements, blood glucose, insulin and lipids. One double-blind RCT was carried out on healthy male volunteers [146]. A large double-blind RCT looked at the impact of 1.5g/day of Nigella seeds in 250 healthy men with metabolic syndrome [147]. One double-blind RCT was carried out on men with obesity [148]. Two studies were carried out with thyroiditis patients [149, 150], four in individuals with metabolic syndrome [151-154], three in patients with hyperlipidemia/hypercholesterolaemia [155-157], three in patients with type 2 diabetes [158-160], and two in patients with NAFLD [161, 162]. The studies on Nigella seeds used between 500mg and 3g/day for durations ranging from 4 weeks to one year.

Nigella seeds improved anthropometric measurements such as BMI and weight in three out of seven studies that included them (at doses of 2 -3g/day), improved blood glucose in five out of ten studies (at doses of 500mg – 2g/day), insulin (at 2g/day) in three out of four studies, blood lipids in seven out of 11 studies (at 500mg - 2g/day) and inflammatory markers in one out of four studies (at a dose of 2g/day). Of the 17 studies, 13 were high-quality according to Jadad.

3.12. Rosemary

The one high-quality, double-blind RCT on rosemary found no impact on liver enzymes, anthropometric measurements, fasting blood glucose, insulin and blood lipids from 4g/day for 8 weeks in patients with NAFLD [163].

3.13. Sage

One low-quality, non-randomized cross-over study found that drinking 600ml of sage tea daily for 4 weeks improved lipid profile but had no effect on blood glucose in healthy female volunteers aged 40-50 years [164].

3.14. Turmeric

Four out of the eleven studies on turmeric looked at patients with type 2 diabetes [165-168]. One turmeric study was carried out on healthy volunteers to investigate glycaemic effect [169]. Three other studies were carried out on individuals who were stated to be overweight, obese or prediabetic, with no other health issues [90, 170, 171]. Two studies looked at the effect of turmeric on NAFLD [172, 173]. The studies used between 1 and 3g/day for between 4 and 12 weeks, or single doses of 1g [90] and 6g [170].

All studies were high quality according to Jadad. Three out of five studies investigating anthropometric measurements such as weight and BMI found some positive effect from turmeric (at a dose of 2.1g/day). Four out of seven studies found improvements in blood glucose levels (at doses of 2.1 - 2g/day), one out of two studies found improvements in insulin (from a dose of 2g/day) and five out of six studies found improvements in blood lipids such as triglycerides, total cholesterol and LDL (at doses of 2.1 – 2.4g/day). Out of three studies looking at inflammatory markers, two found beneficial effects from 2.1-2.4g/day of turmeric powder in capsules.

3.15. Herb/spice efficacy

Figure 2 identifies the main health markers measured and whether effects were seen for each of the herbs and spices in all studies and only in high-quality studies. Blood glucose and insulin were the most commonly measured markers, followed by blood lipids, then inflammatory markers. Only including high-quality studies did not make a big difference to the pattern of responses seen for glucose, insulin or inflammatory markers. However, the benefits of fenugreek and garlic on blood lipids were not apparent when only high-quality studies were considered.

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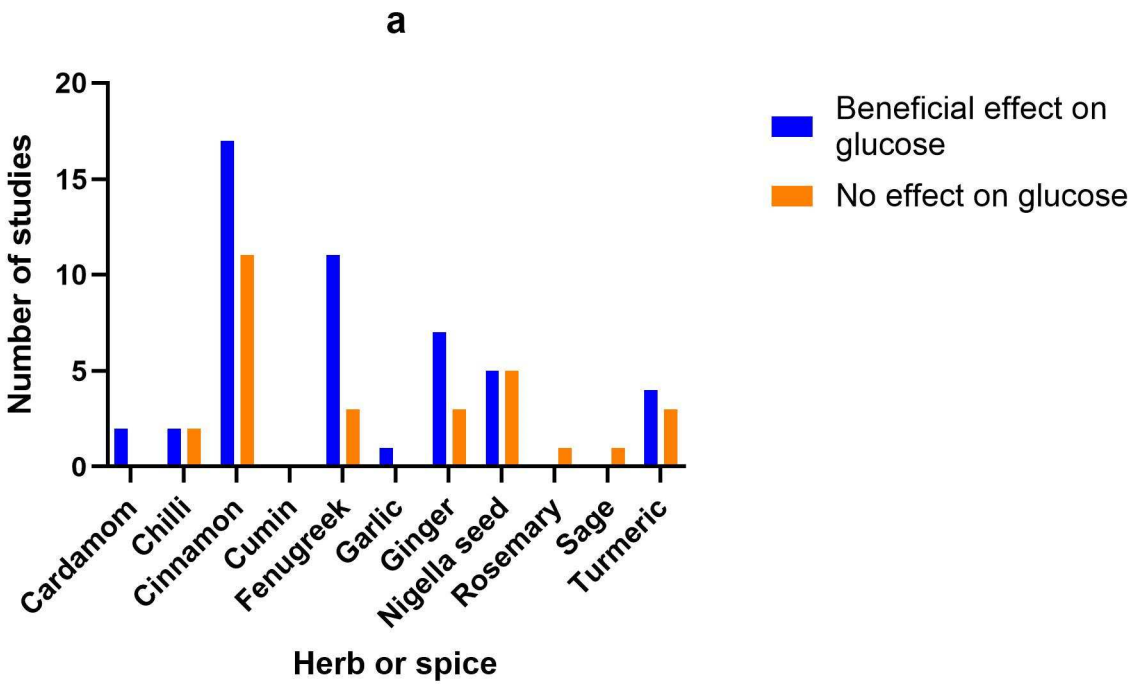

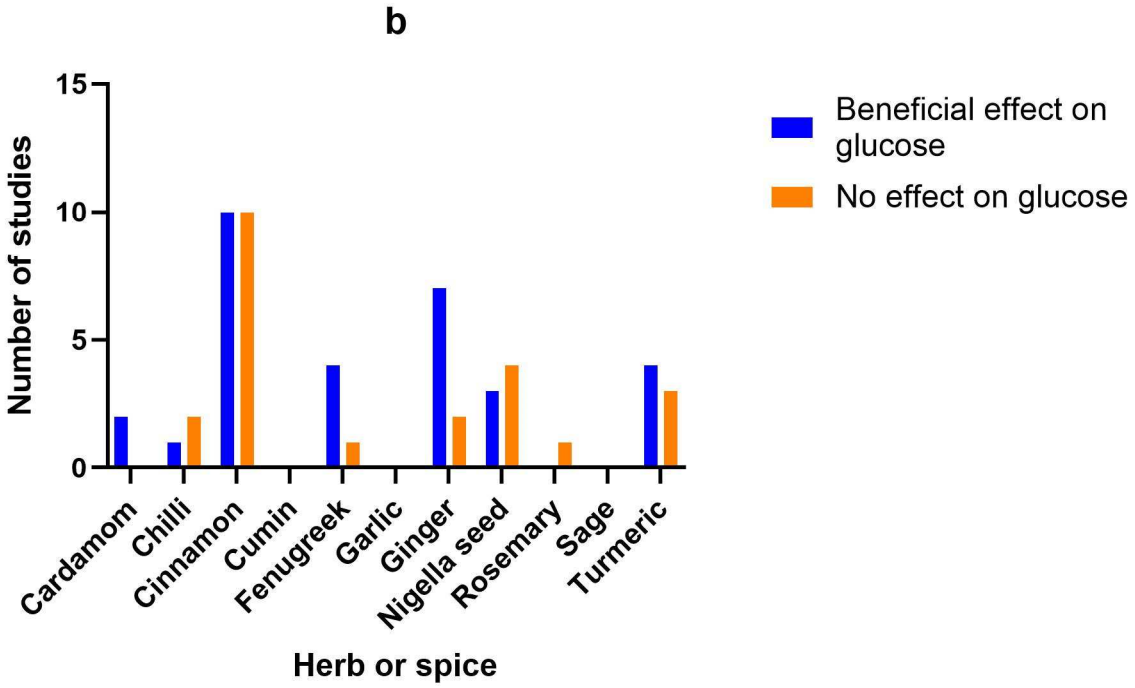

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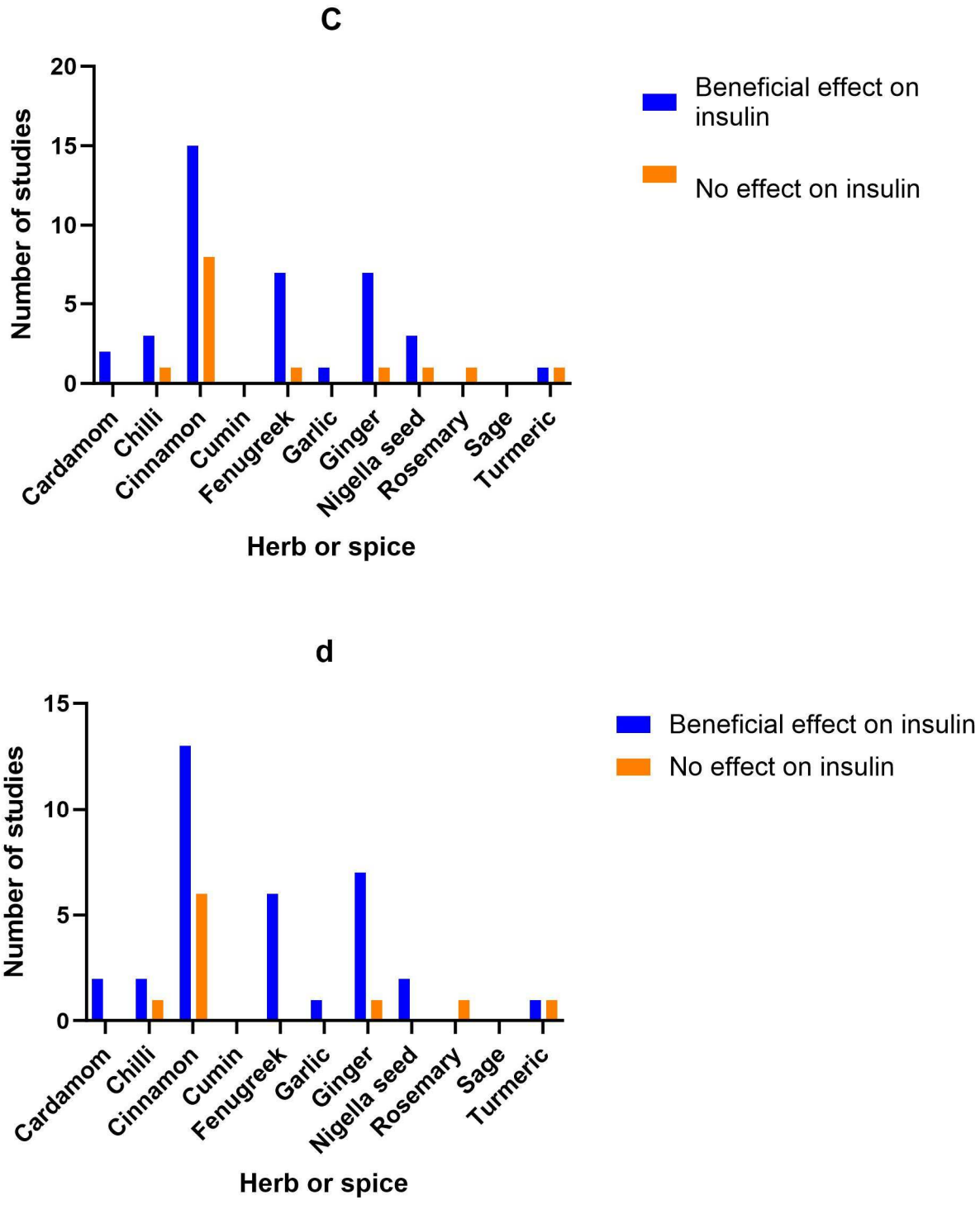

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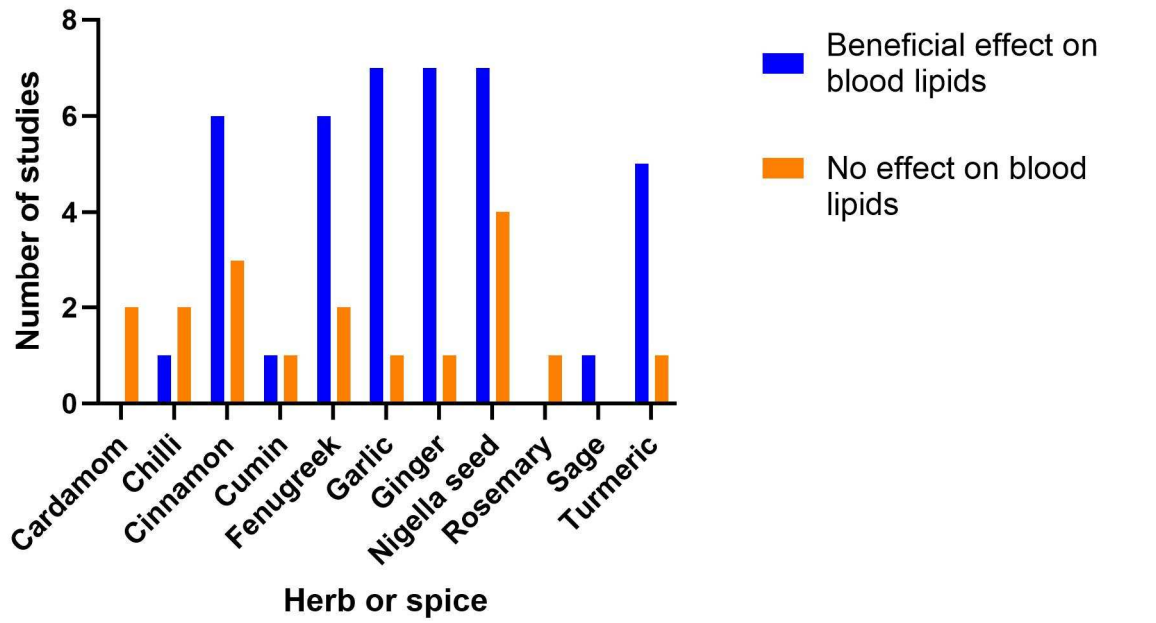

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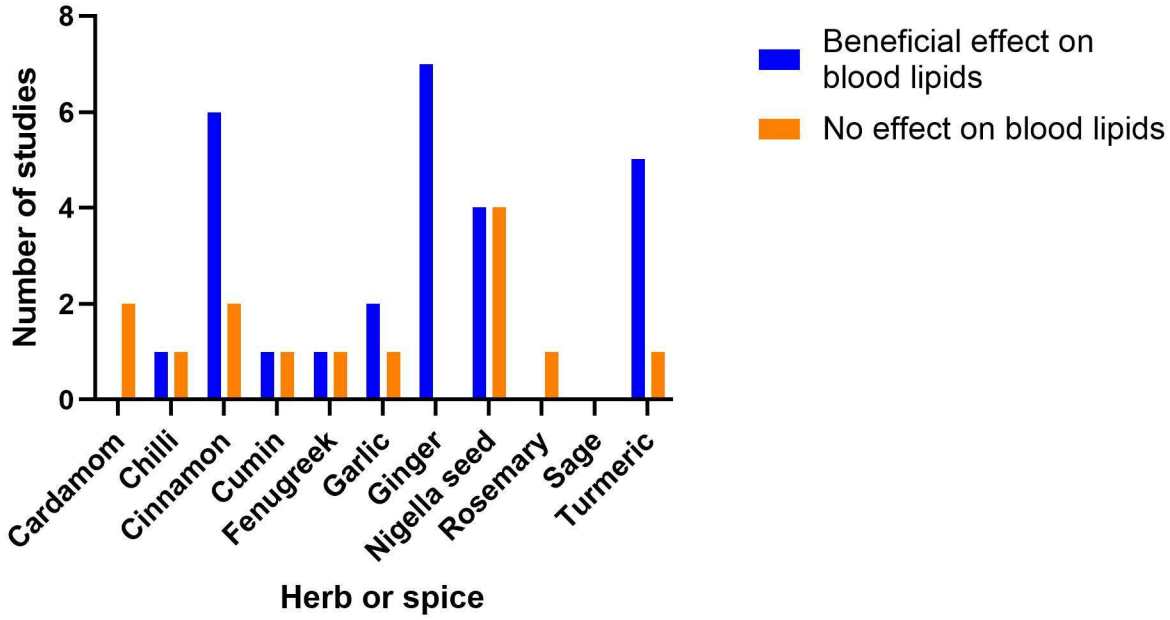

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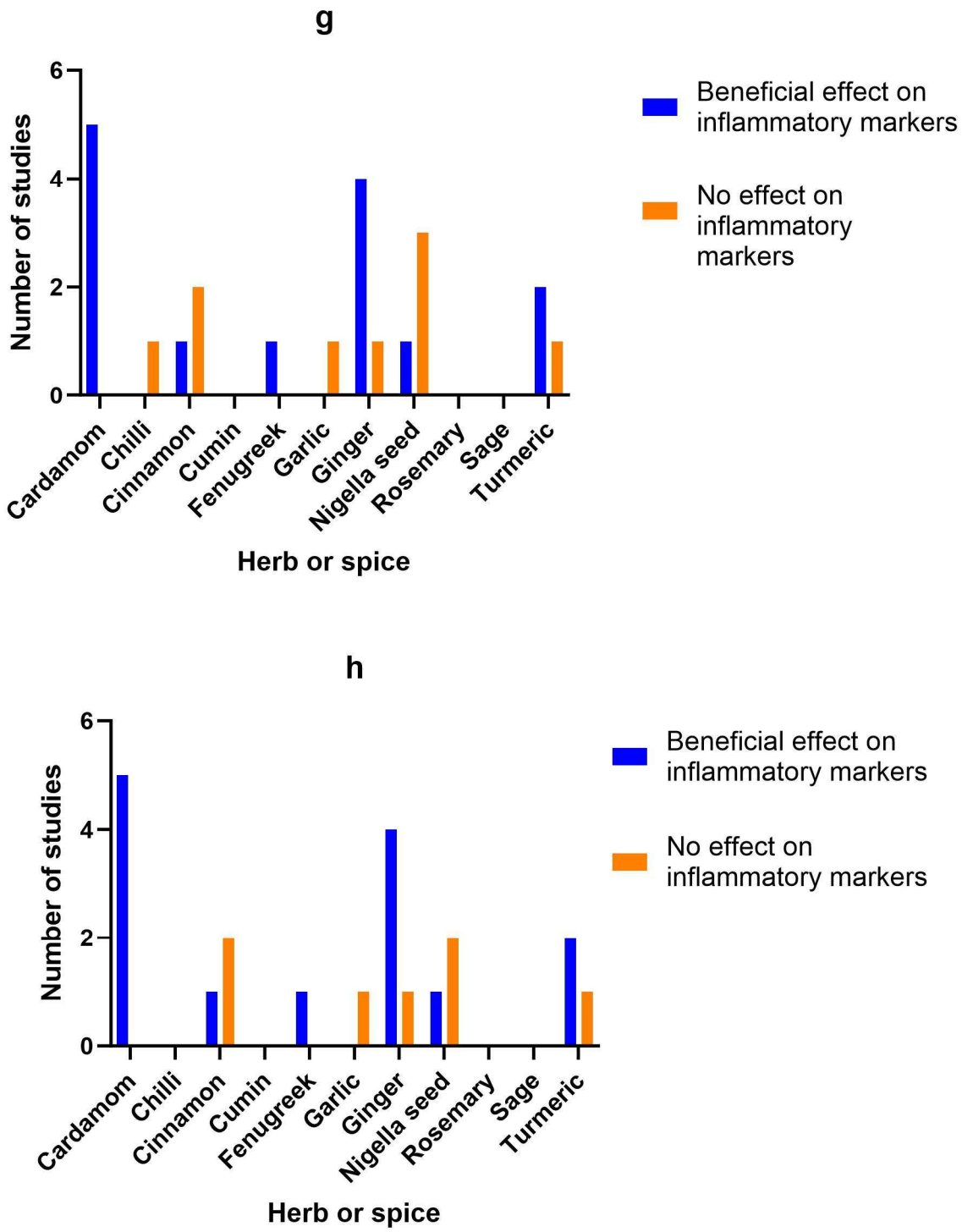

Figure 2. Number of studies and high-quality studies demonstrating an effect of herbs/spices in specific cardiometabolic biomarkers.

Figure 2 identifies the main health markers measured and whether effects were seen for each of the herbs and spices in all studies and only in high-quality studies: (**a**) Number of studies showing an effect or lack of effect for each of the herbs and spices on blood glucose; (**b**) Number of high-quality studies showing an effect or lack of effect for each of the herbs and spices on blood glucose; (**c**) Number of studies showing an effect or lack of effect for each of the herbs and spices on insulin; (**d**) Number of high-quality studies showing an effect or lack of effect for each of the herbs and spices on insulin; (**e**) Number of studies showing an effect or lack of effect for each of the herbs and spices on blood lipids; (**f**) Number of high-quality studies showing an effect or lack of effect for each of the

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herbs and spices on blood lipids; (**g**) Number of studies showing an effect or lack of effect for each of the herbs and spices on inflammatory markers; (**h**) Number of high-quality studies showing an effect or lack of effect for each of the herbs and spices on inflammatory markers.

3.16. Adverse effects

No adverse effects were reported for any of the studies at the doses used.

3.17. Study quality

Studies were scored for quality using Jadad (details on the scores given are provided in Supplementary Table 2). There were 40 low-quality studies (28% of the scored studies), 97 high quality studies (66% of the scored studies), four studies for which there was not enough information to score them and five cohort or observational studies for which quality could not be assessed using the Jadad criteria. Of the 146 studies, 81 were double-blind RCTs, 30 were cross-over clinical studies, 30 were single-blind or parallel clinical studies, two were prospective cohort studies, one was a retrospective cohort study and two were cross-sectional observational studies.

4. Discussion

The aim of this scoping review was to assess the clinical evidence available for culinary doses of herbs and spices, what doses are used and in which health conditions, with a view to identifying areas that need further research. In this review, there were a total of 146 studies looking at the effects of black pepper, chilli, cardamom, cinnamon, cloves, coriander, cumin, fennel, fenugreek, garlic, ginger, Nigella seed, rosemary, sage and turmeric on metabolic health. Cinnamon, fenugreek and ginger showed the most promise on control of blood glucose and insulin. Cinnamon, ginger, Nigella seed and turmeric were most promising for beneficial effects on blood lipid levels. Cardamom, ginger and turmeric showed promise for reducing systemic inflammation due to a decrease in inflammatory markers.

Some herbs/spices were more likely to be researched in a specific population or in an investigation of a specific metabolic biomarker. This either indicates increased efficacy or traditional associations and observations stimulating more research in these areas. Findings from *in vitro* studies or *in vivo* animal research may also have prompted researchers to focus on a particular herb and effect. For example, despite not having a traditional association with inflammation, anti-inflammatory effects of cardamom have been found in an animal model [175].

Cardamom was only investigated in individuals with disease associated with metabolic syndrome and no studies were carried out in healthy individuals. Most studies investigated the impact of cardamom on inflammatory markers. Metabolic syndrome involves increased inflammation, therefore, changes in inflammatory markers are more likely to be observed in those with metabolic syndrome than healthy individuals. Preclinical research has identified the potential of cardamom to be of use in inflammation and hyperlipidaemia. Cardamom reduced swelling and downregulated inflammatory cytokines such as cyclo-oxygenase-2 (COX-2) in an animal model [175]. This confirms the finding in this scoping review that cardamom has anti-inflammatory activity. A terpenoid compound from cardamom, 1,8-cineole, prevented lipid oxidation *in vitro* and lowered serum lipid levels in zebrafish, while cardamom oil at a dose of 3g/kg reduced total cholesterol, LDL-cholesterol and triglycerides in Wistar rats [176]. This scoping review did not identify any clinical studies showing a beneficial effect of cardamom on blood lipids, which may reflect a failure of animal studies to relate to effects in humans, or be due to the difference in dose or formulation.

Almost all the studies of chilli were carried out in healthy individuals. Chilli did not have marked effects on the main insulin, glucose, lipids and inflammatory biomarkers, which may reflect the use of healthy populations for most studies, the doses used or difficulty in blinding chilli consumption in food. It showed more promise for impacting thermogenesis, metabolic rate and appetite. The key active compound in chilli is capsaicin and this binds to transient receptor potential vanilloid receptor 1 (TRPV1) to activate metabolic modulators such as peroxisome proliferator activated receptor (PPAR)α and glucagon-like peptide (GLP)1 (177). Capsaicin has also been found to decrease ghrelin secretion [177], which would explain its appetite-suppressing effects.

The majority of studies of cinnamon were carried out in patients with diabetes, indicating the strong association of this spice with blood sugar control [eg, 178, 179, 180]. This impact on blood

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sugar is thought to be due to an insulin-mimetic effect and via inhibition of digestive enzymes such as α-amylase in the gastrointestinal tract [178, 180]. Cinnamon activates both PPARα and PPARγ, which would explain an effect on glycaemia [181]. However, there was considerable heterogeneity in the effect of cinnamon on blood sugar and blood insulin across the different studies in this review. Cinnamon was more likely to positively impact blood sugar and insulin in healthy individuals than those with type 2 diabetes. Seven out of nine studies (77%) looking at the impact of cinnamon on blood sugar in healthy individuals found a benefit, while only seven out of fifteen studies (47%) looking at the impact of cinnamon on blood sugar in diabetic patients found a benefit. This suggests that it could be of preventative and therapeutic benefit, however, due to the heterogeneity of the results, systematic reviews isolating the impact of dose and health of the participants on outcomes would be interesting. There are a number of meta-analyses of cinnamon in diabetes [178, 181-188]; however, there did not appear to be any assessing blood glucose control in healthy individuals.

The effects on blood sugar, insulin and lipids from cinnamon appeared to be quite mixed from both this scoping review and published meta-analyses. Well-researched areas, such as is found with cinnamon, often highlight heterogenous results. This indicates that further research is needed to separate out the factors that impact on efficacy, such as dose, presence in a food matrix, population or duration of study. Yu et al found that dosage did impact on efficacy, with a dose of less than 1.2g significantly reducing fasting blood glucose, when pooled results found no benefit [181]. There have been at least eight meta-analyses of clinical trials of cinnamon looking at LDL-cholesterol. Six found decreases in LDL-cholesterol [181, 182, 186, 189-191], but two found no impact on LDL-cholesterol [192, 193]. Yu et al found that the effect of cinnamon on LDL-C was influenced by dose [181], which may explain some of the heterogeneity.

Fennel has been used traditionally for its digestive properties [194], but it has also been found to have anti-inflammatory and antihyperlipidaemic activity [20]. Bae et al found that fennel did not impact food consumption, however, it did reduce appetite, indicating that further research might be beneficial [93].

The impact of fenugreek was investigated in patients with diabetes in 14 studies and healthy individuals in six studies. The effects on blood glucose and insulin were mainly positive whether in a healthy or diseased population, however, high-quality studies were less likely to find benefit. Larger doses of fenugreek tended to be used, as the beneficial effect was usually considered to be from the soluble fibre in the seeds [195], although some studies suggest an effect of other compounds such as flavonoids, saponins and the alkaloid trigonelline [196, 197]. As a relatively mild-flavoured spice, larger amounts are palatable in the diet. The studies using larger quantities incorporated the seed powder into a food matrix, such as being baked into bread, therefore they were considered culinary doses and included.

Nine meta-analyses on fenugreek in metabolic syndrome or associated conditions have been published in the last ten years [195-203]. All of those that assessed effects on blood glucose found a benefit, but concerns were raised about the quality of the clinical trials. A review of fenugreek in blood pressure found a dose-dependent effect; with doses greater than 15g/day for longer than 12 weeks being effective [198]. Neelakantan et al also found that dose impacted on the effect of fenugreek on glycaemia, with those higher than 5g being effective [195].

Studies on garlic looked almost exclusively at blood lipid levels whether in healthy populations or those with metabolic disorders. Garlic has a strong association with cardiovascular health and cholesterol levels [204-206], however, much of the published research has looked at the effect of standardised garlic extracts, rather than its consumption in food. Systematic reviews and umbrella reviews have identified strong potential for garlic in hyperlipidaemia, hypertension and inflammation [204-206].

This review has confirmed the benefits of garlic for hyperlipidaemia and indicates that concentrated extracts may not be necessary to benefit from some of the positive health effects from garlic, as both lower and higher doses showed efficacy. There was no relationship between dose and size of effect; for example, the reductions in total cholesterol from 2, 20 and 40g of garlic compared with control were 82, 19 and 51mg/dl, respectively [91, 116, 120]. Both low- and high-quality studies according to Jadad score showed effectiveness. Garlic and its phytochemicals have been found to have anti-hyperlipidaemic activity via 3-hydroxy-3-methylglutaryl CoA (HMG CoA) inhibition and reduction of cholesterol synthesis; hypotensive activity via angiotensin-converting enzyme (ACE)

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inhibition, downregulation of angiotensin II and stimulation of nitric oxide; and, anti-inflammatory/anti-atherosclerotic effects via COX inhibition, decreased synthesis of thromboxane B2, decreased production of leukotriene C4 and reduction of LDL oxidation [207]. There are feasible mechanisms of action for the findings and evidence for the benefits of garlic is building.

Most of the ginger studies in healthy populations looked at thermoregulatory function and appetite rather than metabolic biomarkers of glucose, insulin or lipids. The obvious sensorial heating effects on the body from ginger can explain this choice of research. Activation of TRPV1 by pungent principles in spices such as ginger leads to a sensation of heat in the mouth on consumption and has been suggested to have a thermogenic effect [208]. Studies in diabetic patients appeared largely positive for blood glucose, insulin and lipid levels. Whether this is via activation of TRPV1 receptors, anti-inflammatory effects through inhibition of COX and lipoxygenase or another mechanism remains to be investigated.

Both Nigella seeds and turmeric were investigated in a range of health conditions, with no predominance of either healthy individuals or those with type 2 diabetes. This reflects the broad range of uses of these herbs/spices in traditional medicine.

The studies on Nigella seeds were heterogenous in terms of the populations investigated and effects seen. The health effects are broad and many traditional medicine systems consider it to be a panacea [209-211], which has led to a lack of focus for research into its benefits. However, the phytochemical thymoquinone, found in the essential oil of the seed, has been identified as being responsible for some of the health benefits [209]. This may indicate there is likely to be more benefit from the use of Nigella seed oil than the seeds. A meta-analysis by Daryabeygi-Khotbehsara et al found that there was a reduction of triglycerides by Nigella seed oil, but not the seeds [212]. Sahebkar et al found that Nigella seed powder was more effective than the oil for reducing blood pressure [213], while Askari et al found that the oil was more effective than the powder for blood glucose control [214]. It is likely that thymoquinone and other terpenoids are responsible for supporting with healthy blood lipid and glucose levels, but other phytochemicals not found in the oil are responsible for the hypotensive effect. This indicates the importance of assessing the effect of culinary uses separately from that of concentrated food supplements or extracts. Future research focusing on whether dose and formulation impact on effect and efficacy would be of interest.

There are at least 10 meta-analyses on the use of Nigella seeds for metabolic syndrome and associated conditions [212-221]. These all find benefits of Nigella seeds on anthropometric measurements such as body weight, blood lipids, glucose control and inflammation, apart from a review of studies on patients with NAFLD, which found mixed results on blood lipids, inflammatory markers and glucose control [220].

Most studies on turmeric found a beneficial effect, with the most promising areas being inflammation and blood lipids. A meta-review on the health benefits of turmeric by Rolfe et al identified osteoarthritis and metabolic syndrome to be the most promising areas of research [222]. Turmeric is well researched for its use in inflammatory conditions such as osteoarthritis, however, most research focuses on high-dose curcumin extracts due to the poor bioavailability of curcumin [223]. Therefore, it is interesting that the relatively low doses of 2g were found to have some effect in this review. Sahebkar found in a meta-analysis that overall turmeric reduced CRP, but that bioavailability-improved preparations of curcuminoids were superior [224], so it may be that higher doses are preferable but not essential.

Nearly all of the spices, but none of the herbs, investigated had some evidence to support their use in culinary doses for the prevention or treatment of metabolic syndrome and associated disorders. Four mixed herb/spice intervention studies found metabolic benefits from Italian herb seasoning mixes or mixes containing Mediterranean herbs rosemary, basil, thyme, oregano and parsley [8, 10, 13, 14], however, this scoping review has found a lack of studies to confirm the effects of individual herbs mint, parsley, thyme, rosemary, sage and oregano. These plants are particularly rich sources of volatile oils, therefore, research investigating the antimicrobial properties of the essential oil is abundant [eg, 225, 226]. *In vitro* antimicrobial research is relatively easy to carry out, which may explain why other properties of these herbs have not been investigated to date. In addition to volatile oils, as is the case with the spices cinnamon, turmeric and ginger, these herbs are also good sources of polyphenols [24]. Further research into the general health benefits of adding these herbs to the diet would be beneficial.

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Considering the widespread use of black pepper in food, it was surprising that there was only one study investigating the impact of this popular condiment for health. It may be that flavour prevents the use of large enough quantities in food for this spice to be of benefit. One study of black pepper was excluded as it investigated the use of a water extract made from 20g of black pepper, which was not representative of culinary use [15]. It was not clear from the methodology what final dose was consumed. However, if it was a comparable dose to that used by Gregersen et al [27], then the two studies found opposite effects on appetite, with Zanzer et al finding an effect of black pepper on appetite, but Gregersen et al finding none. Black pepper contains piperine, which is recognised as a phytochemical that enhances absorption of other food components [227], as well as some prescription drugs [228]. The benefits of black pepper could be largely due to its ability to improve bioavailability of polyphenols and other phytochemicals in herb/spice mixtures.

Changes in insulin, blood sugar and blood lipids were the most common biomarkers to be investigated. Effective glycaemic control, whether via eating foods with a low glycaemic index or adding in herbs/spices and other phytochemical-containing plant foods that help to reduce the glycaemic index of foods, is crucial for management and prevention of diabetes, as well as the reduction of cardiometabolic risk factors in diabetics [229]. In terms of coronary heart disease risk, only LDL cholesterol has been proven in formal clinical trials to be a biomarker that can be considered a causative factor. Other factors such as HDL cholesterol, triacylglycerol, vascular function and oxidative damage require further evidence before their measurement can be considered predictive [230]. This scoping review found promise for cardamom, cinnamon, fenugreek, garlic, ginger, Nigella seeds and turmeric, as there were positive findings from at least five different studies for one or more of these biomarkers. However, whether this translates to clinically significant effects for those with metabolic syndrome remains to be seen.

4.1. Limitations and future directions

Heterogeneity in the methodology is a major limiting factor in both interpreting the results of this scoping review and the many systematic reviews that have been carried out in this area. As herbs/spices are complex in terms of phytochemistry, as well as effect, and there are not accepted doses used, comparisons across different studies are challenging.

The doses used in different studies varied more greatly for herbs/spices where both fresh and dried can be used, such as ginger, garlic and chilli. The difficulty in comparing fresh with dried herbs/spices could be overcome in the future by ensuring that phytochemical analysis of fresh versus dried samples is carried out. Methodologies that account for differences such as these will add value and enable clearer comparison of one study with another. Most dried herbs/spices were used in doses of between 1 and 6g, which is representative of the amounts usually used in cooking [however, the doses were usually chosen based on what amounts had been found to be beneficial in previous studies]. A notable exception was fenugreek, which was used in higher doses for the additional fibre benefits. It is possible that investigating higher doses of other herbs/spices may also indicate greater benefit, but this would have to be weighed against palatability.

The combination of multiple herbs and spices is likely to have greater beneficial effect than any individual herb or spice, due to greater quantity and variety of phytochemicals. A limitation of this scoping review is that focusing on individual herbs prevents comparisons being made with the efficacy of herb/spice mixes. Future research could compare the impact of adding a single herb/spice with that from the synergy of a mix of herbs and spices in the diet providing a rich variety of phytochemicals.

The duration of the clinical trials is also likely to be a major limiting factor in determining whether consuming herbs and spices in the diet is likely to have a noticeable effect on metabolic syndrome and cardiovascular health. Although duration of study did not appear to impact on whether the effect was positive or not in the studies included in this review, any dietary intervention for preventative health needs to be assessed over a longer period, which adds considerable cost and complexity to trials. Many of these diseases develop over a long period of time, so the next step should be to measure changes in biomarkers associated with them over longer periods. Identifying metabolite markers that indicate increased consumption of specific herbs may be of use here, as has been suggested for measuring intake of polyphenol-rich foods [231].

The health benefits of herbs/spices are likely due to their phytochemical content and complex interactions between these molecules, other dietary components, the microbiome and the gut wall. Phytochemicals, and polyphenols specifically, have been found to impact carbohydrate absorption and metabolism, gut bacteria populations and uptake of glucose into muscle and adipose tissue [232]. None of the studies incorporated analysis of the phytochemical content of the herbs/spices used, which would have been a useful addition to tease out mechanisms or which bioactive phytochemicals are driving the effects. The impact of any dietary intervention is dependent on multiple other factors, such as the remaining diet, participants' stress levels and physical activity; therefore teasing out the true impact of individual herbs/spices remains a challenge.

5. Conclusions

Overall, this scoping review has highlighted that there is evidence for the beneficial effect of culinary doses of cardamom, cinnamon, chilli, fenugreek, garlic, ginger, Nigella seeds and turmeric in the prevention and treatment of metabolic syndrome and associated disorders. Cardamom, ginger and turmeric appear to have most potential for inflammation linked to metabolic syndrome, garlic, ginger and turmeric for blood lipids, and cinnamon, ginger and fenugreek for blood glucose control. Future research needs to address which factors are most important to unlocking these benefits: the food matrix; combinations of different herbs/spices; duration of consumption; and, how herb/spice intake interacts with other important lifestyle changes.

Supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Excluded papers; Table S2: JADAD scoring.

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Conflicts of Interest: Authors M.M., V.R., and S.M. are employed by Pukka Herbs Ltd, a herbal tea manufacturer.

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