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Beneficial effects of legumes on parameters of the metabolic syndrome: a systematic review of trials in animal models

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Abstract

Legume consumption plays a pivotal role in the prevention and treatment of the metabolic syndrome (MetS). This systematic review aimed to highlight the beneficial effects of legume interventions for the prevention and/or improvement of parameters related to the MetS and the implicated metabolic pathways so far reported. The methodology involved a search in four electronic databases (Medline, Web of Science, Scopus, Cochrane Library) from January 2007 to December 2014, considering as descriptors 'Metabolic Syndrome' and 'Fabaceae' and adequately adjusting the equation in each one of them. In total, forty-one studies were finally included. The majority of the studies described a regulating effect on glucose and lipid metabolism due to legume administration, whereas effects on blood pressure and renal parameters are not fully described. Regarding the metabolic pathways involved, they include the up-regulation of genes related to β-oxidation and acetyl-CoA degradation and the down-regulation of glycolytic and lipogenesis genes, as well as those associated with the acetyl-CoA synthesis. The ameliorating effects of legume consumption on the alterations associated with the MetS are clearly reported and coincide with changes in the expression of protein and genes involved in lipid and glucose metabolism. More research needs to be conducted including more legume species that are highly consumed as part of a healthy dietary pattern.

Key words: Metabolic syndrome: Insulin resistance: Fabaceae: Lipolysis: Metabolic pathways

The metabolic syndrome (MetS) represents a clustering of several metabolic disorders among which central obesity and insulin resistance are considered as causative factors[1,2], affecting one-quarter of the world's adult population[3]. The initial concept of 'Syndrome X' was described by Reaven[4], whereas the most recent diagnostic criteria, as established by the International Diabetes Federation in 2005[5], include obesity (waist circumference ≥ 102 cm in men or ≥88 cm in women), dyslipidaemia (TAG ≥ 150 mg/dl, HDL < 40 mg/dl in men or <50 mg/dl in women), hypertension (≥130 mmHg systolic or ≥85 mmHg diastolic) and alterations of glucose metabolism (>100 mg/dl; includes diabetes)[6]. Although the diagnostic criteria seem to be clear enough, the mechanisms underlying its pathology are not fully understood.

Preventing the development of the MetS requires a multidisciplinary approach, whereas the first step on the treatment of this pathology is focused on the amelioration of the related metabolic alterations and includes mostly lifestyle modifications[7]. Nevertheless, in case such modifications prove to be inadequate, the next movement includes the prescription of appropriate pharmacological agents[8]. Among lifestyle strategies, low-fat/low-glycaemic-index diets and regular physical exercise are encountered[7]. For this reason, legumes have gained increasing interest given that their frequent consumption can help in the control of lipid homoeostasis and, consequently, reduce the risk of CVD. In addition, their consumption is associated with a better glycaemic control in diabetic patients and has exhibited hypolipidaemic effects by reducing the absorption of cholesterol. Their contribution to weight management because of their beneficial effect on appetite-regulating hormones and satiety has also been demonstrated[9,10].

The bioactive compounds that legumes contain such as resistant starch, α galactoside oligosaccharides, phytate, polyphenols and saponins may act as potential physiological modulators of metabolism, given that they inhibit the activity

Abbreviation: MetS, metabolic syndrome.

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of angiotensin-converting enzyme and exhibit prebiotic effects, as well as antioxidant and bile acid-binding properties[11,12], thus showing promising potential as functional ingredients.

Taking into account that the actual lifestyle is at the same time leading to the increase of the prevalence of risk factors that induce the MetS and the undervalued consumption of legume foodstuff, as reflected by epidemiological nutritional surveys, there is a clear need to reinforce lifestyle strategies in order to better prevent the development of the MetS. The present review aimed at gathering the outcomes of recent intervention studies by putting together the beneficial effects that the consumption of different legumes exert on different alterations associated with the MetS.

Methods

Study eligibility

Considering that the aim of the present review was to collect the most recent and representative data for the effects of the legumes on the MetS, we performed a bibliometric analysis in the field of nutrition, which established the period of 7 years as the obsolescence period of the results of these studies[13]. This period assured that more than half of the actual scientific production would be included (Burton–Kebler index: obsolescence according to median age/median production)[14]. Therefore, the cut-off point for the publication date was established from January 2007 to December 2014. Although the present review focused on collecting data of animal trials, no filters were used at this point in order to prevent losing any entry not properly registered. Therefore, further exclusion of the entries was performed manually.

Thus far, the eligibility of the publications was confirmed by fulfilling the following inclusion criteria:

- The research articles should be recent intervention studies published after the year 2007, in which consumption of legume or administration of the legume-derived product was tested against different alterations related to the MetS.
- The research articles should be published in peer review journals, and the ones with complete text access were selected.

Data sources

A comprehensive and systematic review of literature was conducted using four electronic databases: MedLars Online International Literature, via PubMed©, Web of Science, SCOPUS and the Cochrane Library Plus. The first step included the definition of the search terms through the use of Medical Subject Headings (MeSH) and considering as descriptors 'Metabolic Syndrome' and 'Fabaceae', in all the possible forms used by the indexed publications in PubMed. The final equation was ('Metabolic Syndrome X'[Mesh] OR 'Metabolic Syndrome X'[Title/Abstract] OR 'Metabolic Syndrome'[Title/Abstract] OR 'Insulin Resistance Syndrome X'[Title/Abstract] OR 'Syndrome X, Metabolic'[Title/Abstract] OR 'Syndrome X, Insulin Resistance'[Title/Abstract] OR 'Metabolic X Syndrome'[Title/Abstract] OR 'Syndrome, Metabolic X'[Title/Abstract] OR 'X Syndrome, Metabolic'[Title/Abstract] OR 'Dysmetabolic Syndrome X'[Title/Abstract] OR 'Syndrome X, Dysmetabolic'[Title/Abstract] OR 'Reaven Syndrome X'[Title/Abstract] OR 'Syndrome X, Reaven'[Title/Abstract] OR 'Metabolic Cardiovascular Syndrome'[Title/Abstract] OR 'Cardiovascular Syndrome, Metabolic'[Title/Abstract] OR 'Cardiovascular Syndromes, Metabolic'[Title/Abstract] OR 'Syndrome, Metabolic Cardiovascular'[Title/Abstract]) AND ('Fabaceae'[Mesh] OR 'Leguminosae'[Title/Abstract] OR 'Legume'[Title/Abstract] OR 'Legumes'[Title/Abstract] OR 'Beans'[Title/Abstract] OR 'Amorpha'[Title/Abstract] OR 'Andira'[Title/Abstract] OR 'Baptisia'[Title/Abstract] OR 'Callerya'[Title/Abstract] OR 'Ceratonia'[Title/Abstract] OR 'Clathrotropis'[Title/Abstract] OR 'Colophospermum'[Title/Abstract] OR 'Copaifera'[Title/Abstract] OR 'Delonix'[Title/Abstract] OR 'Euchresta'[Title/Abstract] OR 'Guibourtia'[Title/Abstract] OR 'Machaerium'[Title/Abstract] OR 'Pithecellobium'[Title/Abstract] OR 'Pithecolobium'[Title/Abstract] OR 'Stryphnodendron'[Title/Abstract] OR 'Tachigalia'[Title/Abstract] OR 'Afzelia'[Title/Abstract]). The same search strategy was applied for the other three databases, and the equation was suitably adapted. The repeated studies found in the different databases were considered only once in the total list of the studies. The list of eligible studies was completed by the search in the reference list of the publications selected and respecting the *a priori* inclusion criteria established.

Study selection

Two of the authors (R. M. and G. K.) carried out the first screening of the eligible studies separately, which included the review of the abstracts of the studies and the selection of the suitable ones for full-text examination. At this point, bibliographic reviews, epidemiological studies, editorials, case reports and book chapters were excluded. There were no language restrictions. At the second stage of the selection process, the same authors examined the full-text articles and then selected the adequate studies to include. As the aim of the study was to review the existing data on animal intervention studies, the two authors manually excluded the clinical trials in humans. The decisions for the inclusion/exclusion were taken following mutual discussion and consensus. If consensus was not possible, two (M. L.-J. and J. M. P.) more authors examined the articles and the consensus was established after the discussion between the four authors.

Data extraction

After the conclusion of the study selection process, R. M. and G. K. independently reviewed and extracted the data of the selected studies. The overall inter-rater agreement rate before correcting discrepant items was determined using Cohen's κ statistic[15] and established to be superior to 0·80[16]. Any discrepancies were resolved after consensus between the two or four authors (R. M. and G. K.) or between the four of them (including M. L.-J. and J. M. P.) if necessary. The quality of the studies selected was determined by the use of a specific questionnaire for the clinical trials (Scientific studies-clinical trials quality-evaluation questionnaire, CACEC-EC), which is

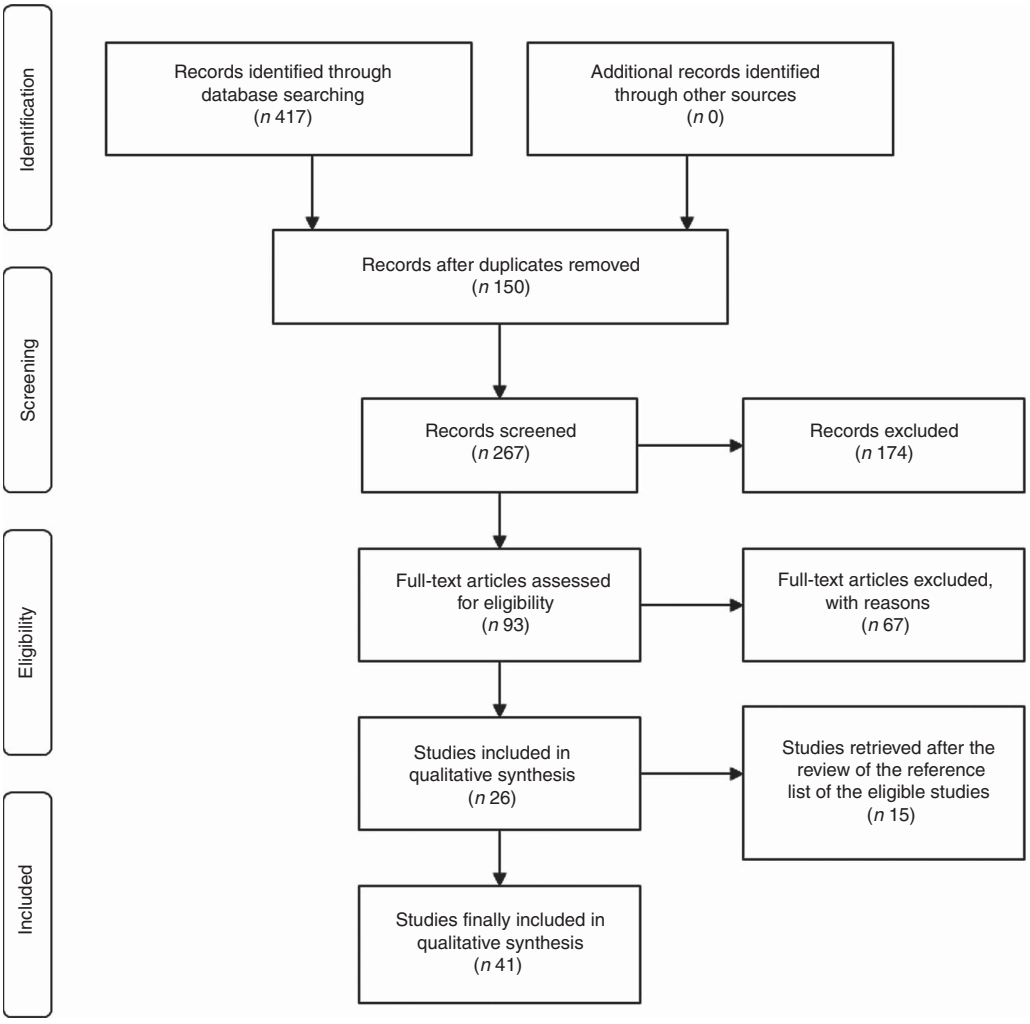

Fig. 1. Flow diagram of the eligible studies included in the systematic review.

divided into two parts: the first part includes filter questions that determine whether the study fulfils the methodology premises of a clinical trial (score > 6) and the second part finally determines the quality (0–6, low; 7–14, good; 15–20, excellent) of the study in its different parts (intervention, sample manipulation, results and conclusions).

The extracted data were grouped in a table and classified according to the legume studied. In the different columns, the reference of the publication, the animal model (number, age and type of animals, experimental groups) used, the intervention (legume type and quantity consumed, technological process and experimental period) followed and the principal beneficial results achieved are noted, in order to facilitate the comprehension of the selected studies.

Results

The initial systematic search in the different electronic databases resulted in 417 references. After the exclusion of duplicated references (*n* 150, among which forty-three clinical trials, forty-nine epidemiological studies, fifty-eight reviews), there were 267 potentially eligible studies remaining. The first screening resulted in exclusion of bibliographic reviews (*n* 92), epidemiological studies (*n* 76) and other types of studies such as book chapters, case reports or editorials (*n* 6 in total). The possibly eligible studies were then reduced to ninety-three. The second screening, which was manually performed, resulted in the exclusion of: trials that studied parameters not relevant with the MetS alterations (*n* 27); clinical trials performed in humans (*n* 30); *in vitro* studies (*n* 8); or finally, animal studies that used legume diet intervention but obtained only negative results due to the specific intervention. After the second screening, twenty-six eligible studies remained, to which fifteen new were added after reviewing the reference lists of the studies already selected. After the whole process was completed, we retracted forty-one eligible studies, which included only *in vivo* experiments in different experimental animal models making use of a legume as part of the diet intervention. The entire process followed is represented in Fig. 1. In total, sixteen different legumes were reported in these studies. The beneficial effects on several parameters of the MetS were collected and are presented in Tables 1 and 2.

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Table 1. Beneficial effects of legumes on several parameters of the metabolic syndrome

References	Animal models	Intervention	Beneficial effects on						
			Glucose metabolism	Lipid metabolism	Blood pressure	BW/ composition	Inflammation markers	Oxidative damage	Renal function
Glycine max/soyabean									
Potu *et al.*[21]	M: female Ossabaw pigs A/W: 3 months	LA: SBO and LLO EP: 8 weeks	–	–	–	–	√	–	–
Mori *et al.*[19]	M: male Wistar rats A/W: 6 weeks	LA: PL from soyabeans EP: 10 weeks	√	√	–	–	–	–	–
Palanisamy *et al.*[26]	M: male Wistar rats MS A/W: 150–160 g	LA: FSD EP: 60 d	√	–	√	√	–	√	√
Ronis *et al.*[17]	M: Sprague–Dawley rats A/W: –	LA: SPI; SPI+; SPI– Expt 1: 33 d	√	√	–	√	–	–	–
Nordentoft *et al.*[20]	M: male KK-A Y and non-diabetic C57/BL mice A/W: 5 weeks	LA: SBP EP: 9 weeks	√	√	–	√	–	–	–
Wagner *et al.*[23]	M: male monkey and obese, hyperinsulinaemic monkey A/W: adult and 8 years	LA: SPI and whole SOY EP: Expt 1: 25 months; Expt 2: 40 weeks	–	√	–	–	–	–	–
Hwang *et al.*[27]	M: obese and lean male Zucker rats A/W: 5 weeks	LA: SP EP: 8 weeks	–	–	–	–	–	–	√
Torre-Villalvazo *et al.*[22]	M: male Sprague–Dawley rats A/W: 4 weeks	LA: SP EP: 180 d	–	√	–	–	–	–	–
Davis *et al.*[24]	M: obese male Zucker diabetic fatty (ZDF/Lepr^{fa}) rats A/W: 6 weeks	LA: SP EP: 11 weeks	√	√	–	√	–	–	√
Zhou *et al.*[25]	M: FVB/N mice A/W: 5–6 weeks	LA: SPIs; SPC; EP: 8 weeks	√	–	–	√	–	–	–
Barrios-Ramos *et al.*[18]	M: male Wistar rats A/W: 250–260 g	LA: oat, soyabean, cocoa, fish oil EP: 14 weeks	√	√	√	–	–	–	–
Trigonella foenum graecum/fenugreek									
Muraki *et al.*[28]	M: male Sprague–Dawley rats A/W: 3 weeks	LA: FSP EP: 12 weeks	√	–	–	–	–	–	–
Belguith-Hadriche *et al.*[30]	M: male Wistar rat A/W: 120 g	LA: EAES EP	–	√	–	–	–	√	–
Kannappan & Anuradha[33]	M: male Wistar rats A/W: 150–180 g	LA: FPEt EP: 45 d	√	–	–	–	–	–	–
Ramadan *et al.*[29]	M: male Wistar rats. Diabetes, obese and immunosuppressive A/W: 125–135 g	LA: FSP EP: 4 weeks	√	√	–	√	√	√	–
Mowla *et al.*[32]	M: male Wistar rats A/W: 150–250 g	LA: ethanolic seed extract EP: 2 h	√	–	–	–	–	–	–
Srichamroen *et al.*[34]	M: male Sprague–Dawley rats A/W: 175–200 g	LA: GAL from seeds EP: 3 weeks	√	√	–	√	–	–	–
Srichamroen *et al.*[35]	M: genetically lean and obese JCR rats A/W: 4 months	LA: GAL EP: 14 d	√	–	–	–	–	–	–
Eidi *et al.*[31]	M: male Wistar rats A/W: 200–250 g	LA: ethanolic extract from seeds EP: 14 d	√	√	–	–	√	–	√

Table 1. *Continued*

References	Animal models	Intervention	Beneficial effects on						
			Glucose metabolism	Lipid metabolism	Blood pressure	BW/ composition	Inflammation markers	Oxidative damage	Renal function
Phaseolus vulgaris/beans									
Zaru *et al.*[39]	M: male Wistar rats A/W: 300 g	LA: *Pv* and *Cs* EP: 17 d	√	–	–	–	–	–	–
Adel & El-shinnawy[36]	M: male Wistar rats A/W: 150–160 g	LA: beans. Hulls, fibre MCC EP: 10 d	√	√	–	√	–	–	–
Zhu *et al.*[38]	M: female Sprague–Dawley rats and C57BL/6J obese male mice A/W: 19 and 27 d	LA: dry red bean EP: 15, 7, 12 d and 7 weeks	–	√	–	√	–	–	–
Carai *et al.*[37]	M: male Zucker *fa/fa* rats A/W: 525 g	LA: dry extract EP: 5 d	√	–	–	√	–	–	–
Vigna angularis/adzuki beans									
Kitano-Okada *et al.*[42]	M: male Fischer 44 rats A/W: 7 weeks	LA: 1 % w/w bean extract EP: 4 weeks	–	√	–	–	–	–	–
Itoh & Furuichi[40]	M: KK-A Y mice A/W: 5, 8 and 3 weeks	LA: CEL or EtEx: mg/kg per d EP: 7, 4 and 1 weeks	–	√	–	–	–	–	–
Itoh *et al.*[41]	M: male Sprague–Dawley rats A/W: 5 weeks/40–60 g	LA: adzuki bean extract EP: 2 weeks	√	√	–	–	–	–	√
Pissum sativum/yellow pea									
Eslinger *et al.*[43]	M: male Sprague–Dawley induced obesity. A/W: 5 weeks	LA: yellow pea-derived fractions OFS, PF, PFL and PS EP: 6 weeks	√	√	–	√	–	–	–
Marinangeli *et al.*[44]	M: male golden Syrian hamsters A/W: 2 weeks	LA: yellow pea EP: 28 d	√	–	–	–	–	–	–
Astragalus membranaceus									
Gao *et al.*[45]	M: male prediabetic rats A/W: 8 weeks/170–190 g	LA: saponins from roots; JQ-R EP: 4 weeks	√	√	–	√	–	–	–
Hoo *et al.*[46]	M: male C57BL/KsJ db/db A/W: 10 weeks	LA: dry root (Rx, 2 g/kg per d) EP: 12 weeks	√	√	–	–	√	–	–
Glycyrrhiza glabra									
Yoke *et al.*[48]	M: male Sprague–Dawley rats A/W: 6 weeks	LA: GA 100 mg/kg EP: 24 h	√	√	–	–	–	–	–
Aoki *et al.*[47]	M: female C7BL/6J mice A/W: 18 weeks	LA: LFO EP: 8 weeks HFD + 8 weeks LFO	√	√	–	√	–	–	–
Other legumes									
Beltrán-Debón *et al.*[60]	M: C57BL/6J male mice A/W: 10 weeks	LA: *Aspalathus linearis* extracts EP: 14 weeks	–	√	–	–	–	–	–
Dai *et al.*[52]	M: male Syrian Hamsters A/W: 4 weeks	LA: *Cajanus cajan* L. (Pigeon pea) EP: 8 weeks	–	√	–	–	–	√	–
Tzeng *et al.*[58]	M: 3T3-L1 adipocytes/old Wistar rats A/W: 8 weeks	LA: *Cassia tora* Seeds: ethanol extract EP: 8 weeks	–	√	–	√	–	–	–

Table 1. *Continued*

References	Animal models	Intervention	Beneficial effects on						
			Glucose metabolism	Lipid metabolism	Blood pressure	BW/ composition	Inflammation markers	Oxidative damage	Renal function
Weidner *et al.*[56]	M: male C57BL/6 mice; leptin receptor-deficient db/db mice and male C57BL/6 A/W: 6, 9 and 9 weeks	LA: *Glycyrrhiza foetida Amorpha fruticosa* EP: 3 weeks; 3 and 15 weeks	√	√	–	√	√	–	–
Boualga *et al.*[61]	M: male Wistar rats A/W: 60–70 g	LA: *Lens culinaris*/*Cicer arietinum* LP/CPr EP: 28 d	–	√	–	√	–	–	–
Okwuosa *et al.*[53]	M: male albino Wistar rats A/W: 100–130 g	LA: *Pterocarpus santaniloides* AEPS MEPS EP: 10 d	√	√	–	–	–	–	–
Peng *et al.*[54]	M: female pups of SP-SHR A/W: 4 weeks	LA: *Pueraria lobata* (kudzu) EP: 2 months	√	√	√	–	–	–	–
Shahraki *et al.*[55]	M: male Wistar rats A/W: 130–150 g	LA: *Tamarindus indica* Seed: aqueous extract EP: 8 weeks	–	√	–	√	–	–	–
Pavana *et al.*[57]	M: albino Wistar male rats: induced DM by streptozotocin A/W: 150–200 g	LA: *Tephrosia purpurea* leaves (TpALet) EP: 45 d	√	√	–	–	–	–	–

BW, body weight; M, model; A/W, age/weight; LA, legume administration; SBO, soyabean oil; LLO, low α-linolenic soyabean oil; EP, experimental period; –, no effect; √, positive effect; FSD, soya protein concentrate; SPI, soya protein isolate; SBP, high content isoflavone soya protein; SP, soya protein; SPIs, isoflavone-depleted soya protein isolates; SPC, soya phytochemicals extract; FSP, fenugreek seed powder; EAES, ethyl acetate extract from seeds; FPEt, polyphenols from seeds; GAL, galactomannan; MCC, mycrocrystalline cellulose; CEL, cellulose; OFS, oligofructose; PF, yellow pea fibre; PFL, yellow pea flour; PS, yellow pea starch; JQ-R, refined JinQi-JiangTang tablet; GA, glycyrrhizic acid; LFO, licorice flavonoid oil; HFD, high-fat diet; LP, lentil protein; CPr, chickpea protein; AEPS, aqueous extract of *Pterocarpus santaniloides*; MEPS, methanolic extract of *Pterocarpus santaniloide*; SP-SHR, stroke prone – spontaneously hypertensive rat.

Table 2. Beneficial effects of legumes on different parameters of the metabolic syndrome expressed as numerical data (Mean values and standard deviations; mean values with their standard errors)

BR*	Beneficial effects on	Results			
Glycine max					
		Groups			
Potu *et al.*[21]		CT (*n* 4)	SBO (*n* 4)	LLO (*n* 4)	Pooled SEM
	Inflammation markers				
	C-reactive protein	101·4	45·8	65·3	8·2

		Groups					
		CT (*n* 6)		F-diet (*n* 6)		F-PL diet (*n* 6)	
Mori *et al.*[19]		Mean	SD	Mean	SD	Mean	SD
	Glucose metabolism						
	AUC glucose (% of CT)	100		138		100	
	G6PDX gene expression	1·00	0·23	2·18	0·39	0·63	0·14
	Lipid metabolism						
	Plasma phospholipids (mmol/l)	11·7	3·4	17·6	4·5	11·7	2·6
	Hepatic TAG (μmol/g)	16·4	1·3	23·9	5·5	16·6	1·1
	Hepatic TC (μmol/g)	10·1	0·3	13·8	1·3	10·1	0·3
	FASN gene expression	1·00	0·30	3·85	0·82	1·96	0·75
	ACACA gene expression	1·00	0·20	2·38	0·28	1·40	0·39
	SCD1 gene expression	1·00	0·25	1·58	0·39	0·98	0·37

		Groups							
		CCD (*n* 6)		FCD (*n* 6)		FSD (*n* 6)		CSD (*n* 6)	
Palanisamy *et al.*[26]		Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Glucose metabolism								
	Plasma glucose (mg/dl)	76·8	11·7	181·2	11·7	84·9	6·2	77·9	5·3
	Plasma insulin (μU/ml)	53·3	3·6	96·8	5·7	58·4	4·2	53·4	3·6
	HOMA	9·39	0·63	42·9	2·7	10·2	0··74	9·05	0·61
	Blood pressure								
	Diastolic pressure (mmHg)	72·1	5·5	94·9	6·2	75·2	6·9	68·7	4·8
	Mean arterial pressure (mmHg)	86·6	6·7	126·3	8·3	91·9	8·4	83·9	5·8
	ACE (U/l)	7·41	0·50	14·34	0·84	8·05	0·58	7·36	0·51
	BW/body composition								
	Final body weight (g)	182·9	12·4	226·5	14·6	205·2	14·9	211·7	14·4
	Oxidative damage								
	TBARS (nmol/mg protein)	1·68	0·12	2·3	0·15	1·80	0·16	1·64	0·11
	GSH (μmol/mg protein)	92·11	6·2	50·84	3·0	85·16	6·2	90·94	6·1
	Renal function								
	Kidney weight (g)	1·95	0·13	2·24	0·14	2·03	0·14	1·93	0·13
	Urine volume (ml/d)	8·81	0·60	17·7	1·1	13·0	0·94	9·50	0·64
	Creatinine (mg/dl)	2·33	0·17	1·78	0·11	2·17	0·19	2·32	0·10
	Plasma total protein (g/dl)	6·1	0·5	4·75	0·31	5·81	0·53	6·14	0·45

Table 2. *Continued*

		Groups					
		CAS (*n* 7–10)		SPI+ (*n* 7–10)		SPI– (*n* 7–10)	
Ronis *et al.*[17]	Expt 1	Mean	SEM	Mean	SEM	Mean	SEM
	Glucose metabolism						
	Glucokinase gene expression						
	Male	1·00	0·24	6·10	1·90	0·94	0·12
	Lipid metabolism						
	ACO gene expression						
	Male	1·00	0·06	1·86	0·08	1·12	0·09
	Female	1·03	0·13	2·93	0·12	1·16	0·18
	CPT-1A expression						
	Male	1·00	0·15	1·74	0·19	0·99	0·15
	Female	0·42	0·05	3·55	0·30	1·28	0·37
	HADHA expression						
	Male	1·00	0·12	1·61	0·19	1·10	0·07
	Female	0·81	0·04	1·46	0·11	2·10	0·40
	PPARα expression						
	Male	1·00	0·08	1·50	0·06	–	
	Female	0·66	0·05	1·18	0·05	–	
	PPARγ expression						
	Male	1·00	0·06	2·20	0·28	–	
	Female	1·04	0·08	1·87	0·13	–	
	CYP/A-1 gene expression						
	Male	1·00	0·19	3·12	0·47	4·60	0·60
	Female	1·45	0·28	3·84	0·29	2·58	0·56
	ABCG5 gene expression						
	Male	1·00	0·16	1·45	0·06	0·63	0·13
	Female	0·41	0·06	2·17	0·28	0·80	0·07
	ABCG8 gene expression						
	Male	1·00	0·17	2·85	0·42	3·34	0·26
	Female	1·25	0·17	4·78	0·86	1·90	0·30
	LXRα						
	Male	1·00	0·04	1·38	0·06	–	
	Female	1·42	0·06	1·48	0·06	–	
		Groups					
		Casein (*n* 7–10)		Wester casein (*n* 7–10)		Wester SPI (*n* 7–10)	
	Expt 2	Mean	SEM	Mean	SEM	Mean	SEM
	Glucose metabolism						
	Serum glucose (mmol/l)	4·50	0·13	5·10	0·17	4·50	0·21
	Lipid metabolism						
	Serum TC (mmol/l)	2·10	0·33	4·40	1·00	2·60	0·36
	Liver weight (g/100 g body weight)	4·10	0·12	4·70	0·17	4·20	0·14
	Liver TAG (μmol/g wet tissue)	44·70	12·70	100·60	14·40	51·20	11·30
	BW/body composition						
	Body weight gain (g/d)	8·10	0·10	9·20	0·10	8·30	0·20
	Body fat mass (%)	14·80	0·80	19·00	0·30	16·00	1·20

Table 2. *Continued*

Wagner *et al.*[23]	Expt 2	Groups: CAS (*n* 8) Mean	CAS (*n* 8) SEM	SOY– (*n* 8) Mean	SOY– (*n* 8) SEM	SOY+ (*n* 8) Mean	SOY+ (*n* 8) SEM
	Lipid metabolism						
	LDL-cholesterol (mg/dl)	106·1	18·5	78·9	15·4	96·3	16·1

Hwang *et al.*[27]		Groups: Lean EW (*n* 9–10) Mean	Lean EW (*n* 9–10) SEM	Lean SP (*n* 9–10) Mean	Lean SP (*n* 9–10) SEM	fa/fa EW (*n* 9–10) Mean	fa/fa EW (*n* 9–10) SEM	fa/fa SP (*n* 9–10) Mean	fa/fa SP (*n* 9–10) SEM
	Renal function								
	Kidney weight (g/100 g BW)	0·71	0·02	0·67	0·01	0·54	0·01	0·50	0·01
	6-Keto $PGF_{1\alpha}$ (ng/min per mg protein)	0·86	0·14	0·83	0·17	1·24	0·21	0·77	0·10

Torre-Villalvazo *et al.*[22]		Groups: CAS (*n* 8) Mean	CAS (*n* 8) SEM	SOY (*n* 8) Mean	SOY (*n* 8) SEM	HF-CAS (*n* 8) Mean	HF-CAS (*n* 8) SEM	HF-SOY (*n* 8) Mean	HF-SOY (*n* 8) SEM
	Lipid metabolism								
	Serum TC (nmol/l)	3·8	0·1	2·1	0·1	4·2	0·1	2·5	0·2
	Serum TAG (nmol/l)	1·2	0·0	0·53	0·0	1·9	0·1	0·58	0·1
	Liver TAG (mmol/g)	0·02	0·0	0·03	0·0	0·06	0·0	0·02	0·0

Davis *et al.*[24]		Groups: CAS (*n* 8–10) Mean	CAS (*n* 8–10) SEM	LIS (*n* 8–10) Mean	LIS (*n* 8–10) SEM	HIS (*n* 8–10) Mean	HIS (*n* 8–10) SEM	CR (*n* 8–10) Mean	CR (*n* 8–10) SEM
	Glucose metabolism								
	Fasting plasma glucose (mmol/l)	15·4	0·85	9·27	0·86	12·6	1·45	11·3	1·66
	Fasting plasma insulin (nmol/l)	0·31	0·04	1·92	0·0·26	0·54	0·23	2·62	0··30
	Glucose:insulin ratio	51·2	7·62	6·26	1·31	28·7	5·23	5·76	1·62
	Lipid metabolism								
	Plasma TAG (mmol/l)	15·0	1·32	6·04	1·25	5·54	0·62	4··84	0·68
	Plasma TC (mmol/l)	6·39	0·45	2·65	0·15	2·42	0·19	3·64	0·32
	Liver weight (g)	27·9	1·57	26·2	1·52	18··9	1·15	28·4	1·72
	Liver TAG (μmol/g)	106·7	4·48	112·1	5·21	38·51	4·85	129·2	5·21
	BW/body composition								
	Final body weight (g)	420·0	5·42	486·6	10·3	412·4	17·4	560·5	13·6
	Total body lipid (g)	173·0	6·73	196·8	21·2	151·4	10·4	228·4	16·9
	Renal function								
	Kidney weight (g)	1·90	0·057	1·52	0·059	1·68	0·051	1·52	0·059
	Total urine volume (ml)	134	11·5	65·1	11·4	129	13·8	55·5	17·8
	Total urine protein (mg/ml)	1·22	0·155	0·56	0·097	0·45	0·072	0·60	0·155
	Urine creatinine (μmol/l)	17·6	4·32	70·3	10·2	26·1	5·02	69·0	19·3

Table 2. *Continued*

		Groups											
		–CT (*n* 8)		+CT (*n* 8)		Co (*n* 8)		S (*n* 8)		O (*n* 8)		Ω (*n* 8)	
Barrios-Ramos *et al.*[18]		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
	Glucose metabolism Serum glucose (mg/dl)	96·4	10·3	124·8	6·3	84·6	7·2	–		–		91·8	9·1
		Co + S (*n* 8)		Co + O (*n* 8)		Co + Ω (*n* 8)		CoSO Ω (*n* 8)		CoSOΩ ASM (*n* 8)		CoSOΩ BSM (*n* 8)	
		–		–		–		–		93·5	3·7	–	
		–CT (*n* 8)		+CT (*n* 8)		Co (*n* 8)		S (*n* 8)		O (*n* 8)		Ω (*n* 8)	
	Lipid metabolism Total cholesterol (mmol/l)	14·2	0·95	86·4	12·0	–		68·2	7·7	–		–	
		Co + S (*n* 8)		Co + O (*n* 8)		Co + Ω (*n* 8)		CoSO Ω (*n* 8)		CoSOΩ ASM (*n* 8)		CoSOΩ BSM (*n* 8)	
		–		–		–		–		–		–	
	HDL-cholesterol (mmol/l)	–CT (*n* 8)		+CT (*n* 8)		Co (*n* 8)		S (*n* 8)		O (*n* 8)		Ω (*n* 8)	
				6·7	0·64	4·5	0·16	3·1	0·72	4·0	0·52	3·9	0·25
		Co + S (*n* 8)		Co + O (*n* 8)		Co + Ω (*n* 8)		CoSO Ω (*n* 8)		CoSOΩ ASM (*n* 8)		CoSOΩ BSM (*n* 8)	
		5·1	0·25	–		4·3	0·40	–		–		3·5	0·36
	LDL-cholesterol (mmol/l)	–CT (*n* 8)		+CT (*n* 8)		Co (*n* 8)		S (*n* 8)		O (*n* 8)		Ω (*n* 8)	
		6·5	1·01	79·0	12·3	–		–		–		–	
		Co + S (*n* 8)		Co + O (*n* 8)		Co + Ω (*n* 8)		CoSO Ω (*n* 8)		CoSOΩ ASM (*n* 8)		CoSOΩ BSM (*n* 8)	
		–		–		–		–		–		–	
		–CT (*n* 8)		+CT (*n* 8)		Co (*n* 8)		S (*n* 8)		O (*n* 8)		Ω (*n* 8)	
	TAG (mmol/l)	0·68	0·05	1·54	0·11	0·57	0·06	0·87	0·09	0·73	0·11	0·68	0·08
		Co + S (*n* 8)		Co + O (*n* 8)		Co + Ω (*n* 8)		CoSO Ω (*n* 8)		CoSOΩ ASM (*n* 8)		CoSOΩ BSM (*n* 8)	
		0·80	0·09	0·80	0·05	0·90	0·16	0·82	0·07	0·92	0·04	1·18	0·09
		–CT (*n* 8)		+CT (*n* 8)		Co (*n* 8)		S (*n* 8)		O (*n* 8)		Ω (*n* 8)	
	Steatosis (%)	0		29·9	1·32	–		8·5	1·09	–		–	
		Co + S (*n* 8)		Co + O (*n* 8)		Co + Ω (*n* 8)		CoSO Ω (*n* 8)		CoSOΩ ASM (*n* 8)		CoSOΩ BSM (*n* 8)	
		4·71	0·69	6·29	0·74	21·08	1·64	55·04	1·34	10·11	0·68	–	

Trigonella foenum graecum/fenugreek

		Groups					
		STD (*n* 6)		HFS (*n* 6)		Fen (*n* 6)	
Muraki *et al.*[28]		Mean	SEM	Mean	SEM	Mean	SEM
	Glucose metabolism HOMA-IR	1·00	0·34	2·30	0·31	1·32	0·24

Table 2. *Continued*

Kannappan & Anuradha[33]	Groups									
	CON (*n* 6)		FRU (*n* 6)		FRU + FPEt (*n* 6)		FRU + Quer (*n* 6)		FRU + Met (*n* 6)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Glucose metabolism										
Plasma glucose (mM)	4·51	0·21	7·15	0·15	5·66	0·21	5·22	0·37	4·69	0·27
Plasma insulin (μU/ml)	46·58	3·87	83·10	6·37	65·38	3·88	60·03	4·60	50·06	4·20
HOMA	9·32	0·76	26·44	1·39	15·63	0·96	13·23	0·83	10·48	0·81
QUICKY	0·283	0·017	0·248	0·019	0·257	0·012	0·267	0·021	0·275	0·019
$ISI_{0,120}$	129·03	9·87	60·87	3·56	84·06	4·29	105·11	5·88	121·47	7·35
AUC glucose (mg/ml per min)	159·5	11·23	271·94	21·60	203·47	12·45	193·5	11·30	175·70	9·30
AUC insulin (mg/ml per min)	10 021	823	16 652	1060	12 990	993	11 904	1030	10 649	956
Hexokinase†	0·839	0·02	0·392	0·01	0·656	0·0010	0·701	0·009	0·815	0·04
Pyruvate kinase‡	113·27	6·53	69·83	4·39	80·88	5·05	92·06	8·42	106·32	8·27
G6Pase§	4·21	0·24	7·94	0·21	6·31	0·22	5·32	0·25	4·53	0·34
F1,6BPase§	4·75	0·19	8·84	0·52	6·18	0·29	5·60	0·24	5·02	0·21
GP‖	4·11	0·21	7·44	0·30	6·43	0·29	5·47	0·45	4·40	0·27
Glycogen (mg Glu/g tissue)	54·78	5·21	32·14	3·12	39·91	3··85	45·54	3·93	51·59	5·00
ICDH‖	741·2	28·8	538·8	26·1	628·5	20·5	668·5	29·8	710·3	15·6
SDH (mg glucose/g tissue)	28·74	2·56	11·49	0·96	15·74	0·99	18·91	1·58	26·23	1·94
PTP (A_{620})	0·458	0·02	0·731	0·04	0·595	0·03	0·567	0·02	0·475	0·02
PTK (A_{492})	0·672	0·04	0·335	0·01	0·597	0·04	0·637	0·03	0·659	0·02
Lipid metabolism										
Plasma TAG (mg/dl)	89·01	4·20	163·42	5·39	128·40	6·08	117·47	8·63	94·30	3·34
Plasma NEFA (mg/dl)	25·68	2·42	72·24	6·35	58·12	4·69	47·99	2·56	31·17	2·67

Ramadan *et al.*[29]	Groups																	
	CT (*n* 5)		0·5 FSP (*n* 5)		1·0 FSP (*n* 5)		Allx (*n* 5)		Alloxan + 0·5 FSP (*n* 5)		Allx + 1FSP (*n* 5)		CHOL (*n* 5)		CHOL + 0·5 FSP (*n* 5)		CHOL + 1·0 FSP (*n* 5)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism																		
Serum glucose (mg/l)	930	45	834	9	751	4	3028	52	1847	12	1163	16	1512	21	1177	12	1033	12
Lipid metabolism																		
Liver weight:BW ratio	0·0304	0·0010	0·0322	0·0004	0·0326	0·0010	0·0327	0·0002	0·0315	0·0003	0·0310	0·0001	0·0422	0·0007	0·0398	0·0003	0·0380	0·0003
Serum total lipids (mg/l)	4614	178	4500	148	3592	125	7047	141	6319	126	5485	75	8064	102	5943	118	5479	99
TC (mg/l)	586	21	534	10	519	4	855	26	748	8	705	7	1403	14	908	10	819	11
TAG (mg/l)	522	6	444	12	345	4	1130	23	975	8	754	6	1110	18	935	13	686	13
Atherogenic index¶	1409	0·022	1241	0·007	1177	0·002	3478	0·086	2924	0·086	2084	0·028	4272	0·079	2665	0·026	1991	0·010
Atherogenic index**	0·157	0·018	0·034	0·007	0·020	0·002	1557	0·055	1161	0·046	0·638	0·022	2596	0·071	1116	0·023	0·657	0·010
BW/body composition																		
Body weight gain or loss (g)	37·4	0·7	39·0	0·3	39·6	0·7	−14·2	0·6	7·4	0·4	20·0	0·8	78·4	0·9	65·6	0·7	51·4	1·1
Inflammation markers																		
ALAT activity (IU/l)	29·8	1·1	27·5	0·6	24·3	0·8	90·0	1·0	69·2	0·8	37·6	0·5	91·7	3·2	66·8	1·0	39·3	1·1
ASAT activity (IU/l)	39·2	2·2	36·1	0·8	34·4	1·1	148·6	1·7	84·8	1·1	63·2	1·2	126·6	2·1	65·1	1·5	44·0	1·2
ALP activity (IU/l)	29·0	1·4	27·7	1·2	24·6	0·7	101·0	2·3	59·4	1·8	41·2	1·1	45·1	0·5	39·5	0·9	37·4	0·8
Oxidative damage																		
GSH (nm/g tissue)	10·2	0·3	12·1	0·2	13·5	0·4	2·5	0·1	3·7	0·2	4·4	0·1	8·9	0·1	10·5	0·2	11·3	0·3

Table 2. *Continued*

Mowla *et al.*[32]		Groups							
		Non-diabetic (*n* 5)		Water control (*n* 5)		Glimepiride (*n* 5)		Extract (*n* 5)	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism									
Blood glucose (mg/dl)									
	Extract 2 g/kg	61·83	2·15	96·35	3·6	62·38	2·8	63·67	2·8
	Extract 1 g/kg	64·95	1·15	101·27	3·11	43·35	1·75	61·45	1·88
	Extract 500 mg/kg	58·65	6·5	86·23	3·6	50·38	7·8	75·53	5·2
	Extract 100 mg/kg	60·23	1·5	88·50	5·6	58·65	3·5	80·78	2·9

Srichamroen *et al.*[34]		Groups					
		Control (*n* 5)		Low GAL (*n* 5)		High GAL (*n* 5)	
		Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism							
	AUC (plasma glucose)	1361·5	12·5	1310·9	12·5	1239·9	12·5
	AUC (plasma insulin)	12·1	0·3	10·1	0·3	7·1	0·3
Lipid metabolism		Plasma TAG, TC, NEFA, VLDL, LDL, HDL, hepatic TAG, cholesterol and epididymal TAG represented by chart					
BW/body composition							
	Body weight gain (g)	165·8	9·7	157·4	10·3	124·2	10·3
	Epididymal adipose tissue (g)	5·90	0·3	4·57	0·3	2·58	0·3
	Perirenal adipose tissue (g)	1·38	0·1	1·23	0·1	0·91	0·26

Phaseolus vulgaris

Adel & El-shinnawy[36]		Groups											
		NC (*n* 6)		Or (*n* 6)		MCC-PS (*n* 6)		H (*n* 6)		HO (*n* 6)		HMCC-PS (*n* 6)	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism													
	Serum insulin (μmol/ml)	1·68	0·07	1·42	0·06	1·55	0·01	4·17	0·17	1·81	0·13	1·86	0·34
	Glucose (mg/dl)	33·80	5·49	34·80	4·63	22·90	5·10	63·20	4·44	16·00	0·89	17·70	0·88
Lipid metabolism													
	Serum TC (mg/dl)	75·02	1·22	65·72	0·74	69·03	4·31	161·19	1·45	119·88	4·78	112·66	6·86
	Serum TAG (mg/dl)	60·11	1·06	73·0	1·67	59·39	4·22	142·95	11·81	79·99	7·97	61·97	2·28
	HDL (mg/dl)	44·58	1·77	39·50	0·72	42·52	2·20	64·19	5·22	35·69	1·78	30·52	2·38
	LDL (mg/dl)	20·82	1·70	14·53	0·82	17·0	3·56	74·12	3·45	71·39	5·36	70·27	4·94
	Phospholipids (mg/dl)	449·10	17·77	487·80	33·67	418·75	36·46	1798·20	96·5	542·25	20·77	613·25	34·10
BW/body composition													
	Final body weight (g)	276·60	17·04	271·40	14·98	243·88	15·85	310·60	16·35	265·90	16·54	258·20	15·05
	Body weight gain (g)	126·40	1·77	127·60	3·74	96·60	0·50	169·20	17·22	123·00	14·35	106·80	1·93

Table 2. *Continued*

Zhu *et al.*[38]	Groups: High fat control (*n* 8) 12 d Mean	SEM	7 weeks Mean	SEM	High fat bean (*n* 8) 12 d Mean	SEM	7 weeks Mean	SEM
Lipid metabolism								
TC (mg/l)	57·2	2·3			47·6	0·8		
Total cholesterol (mmol/l)			5·28	0·39			4·32	0·28
LDL-cholesterol (mg/l)	23·5	2·1			14·0	1·0		
Plasma leptin (nmol/l)			1·11	0·21			0·69	0·08
BW/body composition								
Final body weight (g)	56	1			51	1		

Vigna angularis/adzuki beans

Kitano-Okada *et al.*[42]	Groups: C (*n* 5) Mean	SEM	A (*n* 5) Mean	SEM	CF (*n* 5) Mean	SEM	AF (*n* 5) Mean	SEM
Lipid metabolism								
Serum TC (mmol/l)	1·99	0·11	1·64	0·08	1·69	0·09	1·46	0·05
Non-HDL-cholesterol (mmol/l)	1·29	0·08	0·97	0·06	1·06	0·07	0·86	0·03
TAG (mmol/l)	1·08	0·13	0·43	0·09	0·77	0·08	0·54	0·08
Liver weight (g/100 g BW)	2·17	0·06	2·16	0·02	2·3	0·04	2·12	0·03
Liver total lipids (mg liver)	64·4	3·86	66·5	6·66	142	27·4	75·9	10·8
Faecal total lipid (mg/g)	22·3	1·20	21·3	3·22	34·9	5·47	59·8	5·35

Itoh & Furuichi[40]	Groups: High-fat cholesterol diet (*n* 5) C Mean	SEM	EtEx.40 Mean	SEM	High-fat cholesterol-free diet (*n* 5) C Mean	SEM	EtEx.40 Mean	SEM
Lipid metabolism								
Serum TC (mg/100 ml)	150·86	16·81	87·24	6·10				
Serum HDL-cholesterol/TC (%)	2·21	0·11	24·21	0·11				
Phospholipids (mg/100 ml)	123·88	8·72	93·29	5·68				
Dry weight of faeces (g/d)	1·07	0·05	1·62	0·04	1·24	0·09	1·85	0·06
TAG (mg/100 ml)					74·60	9·68	46·20	5·96
Faecal neutral cholesterol (mg/d)					4·93	0·26	11·54	0·67

Table 2. *Continued*

Itoh *et al.*[41]	Groups							
	500 mg/kg per d (*n* 5)				5000 mg/kg per d (*n* 5)			
	Cellulose		EtEx.40		Cellulose		EtEx.40	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism								
Blood glucose (mg/dl)	Data represented by chart							
Plasma insulin (μU/ml)	371·53	54·66	233·83	69·35	371·43	58·12	38·31	8·16
Lipid metabolism								
Liver weight (g)	2·10	0·04	2·19	0·08	2·21	0·06	1·61	0·07
Liver TC (mg/g)	7·41	0·09	7·78	0·23	7·30	0·09	6·78	0·14
Liver TAG (mg/g)	33·68	1·17	31·75	0·82	30·89	0·63	27·25	0·53
Liver phospholipids (mg/g)	16·41	0·25	15·73	0·20	17·37	0·18	20·81	1·30
Renal function								
Urinary glucose	Data represented by chart							

Pissum sativum/yellow pea

Eslinger *et al.*[43]	Groups									
	C (n 8–10)		PF (n 8–10)		PFL (n 8–10)		PS (n 8–10)		OFS (n 8–10)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism										
Plasma glucose (mmol/l), plasma insulin (pmol/l), plasma GLP-1 (pmol/l)	Data represented by chart									
Lipid metabolism										
Liver weight (mg/g)	35·4	2·9	33·3	1·6	31·5	1·9	30·9	1·4	27·5	3·7
Liver TAG (mg/g), ACC and SREBP-1c gene expression	Data represented by chart									
BW/body composition										
Body fat (%)	26·9	1·7	24·0	1·9	20·2	1·4	22·7	0·96	20·9	1·7

Marinangeli *et al.*[44]	Groups					
	C (*n* 15)		WPF (*n* 15)		FPF (*n* 15)	
	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism						
Glucose (mmol/l)	8·27	0·81	6·75	0·39	6·26	0·51
Insulin (mol/l)	131·70	17·70	56·76	9·22	89·27	19·82

Table 2. *Continued*

Glycyrrhiza glabra

Aoki *et al.*[47]	Groups							
	CT (n 10)		0·5 % LFO (n 10)		1 % LFO (n 10)		2 % LFO (n 10)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Glucose metabolism								
Serum insulin (ng/ml)	1·69	0·88	1·73	1·23	0·80	0·50	0·70	0·42
Lipids metabolism								
Serum leptin (ng/ml)	35·3	12·3	35·4	13·5	17·0	7·6	6·54	6·04
Adipose mesenteric weight (g)	0·611	0·160	0·572	0·189	0·419	0·117	0·284	0·115
Adipose periuterine weight (g)	1500	0·415	1444	0·465	0·980	0·360	0·541	0·238
Adipose perirenal weight (g)	0·958	0·248	0·894	0·297	0·589	0·230	0·324	0·187
BW/body composition								
Body weight gain (g/8 week)	6·2	2·2	5·9	1·7	2·4	1·8	0·3	1·9

Cajanus cajan

Dai *et al.*[52]	Groups											
	ND (n 6)		HFD (n 6)		LDP-HFD (n 6)		MDP-HFD (n 6)		HDP-HFD (n 6)		PC-HFD (n 6)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lipid metabolism												
Hepatic mRNA expression of CPT-1, CYP7A1, LDLr and HMG-CoA reductase	Data represented by chart											
Serum TAG, TC, HDL-cholesterol and LDL-cholesterol (mg/dl)	Data represented by chart											
Liver weight (g/100 g of BW)	3·4	0·1	5·1	0·2	4·6	0·2	4·4	0·2	4·6	0·4	3·7	0·1
Hepatic TAG (mg/g)	13·9	0·7	20·3	2·3	16·2	0·9	15·4	0·7	13·7	0·8	12·2	0·6
Hepatic TC (mg/g)	4·9	0·4	10·9	1·8	8·7	0·1	8·2	0·3	7·3	0·1	6·9	0·2
Oxidative damage												
Liver TBARS (nmol MDA/mg protein)	Data represented by chart											

Cassia tora

Tzeng *et al.*[58]	Groups											
	RCD (*n* 8)		HFD (*n* 8)		CSEE 100 (*n* 8)		CSEE 200 (*n* 8)		CSEE 300 (*n* 8)		PG (*n* 8)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lipid metabolism												
Plasma TC (mg/dl)	121	10·2	240	11·3	164	9·5	148	8·7	130	7·3	114	6
Plasma TAG (mg/dl)	89·3	6·2	155	8·3	130	7·1	117	6·5	109	5·8	94·6	6·7
Plasma LDL-cholesterol (mg/dl)	46·7	4·8	162	6·3	94·2	5·2	78·8	5·7	71·8	6·7	50·6	8·3
Plasma HDL-cholesterol (mg/dl)	47·6	4·3	28·9	5·1	36·7	4·6	40·1	4·2	43·3	3·9	45·7	4·1
Plasma NEFA (mg/dl)	29·6	4·9	62·1	5·3	55·4	5·1	49·5	4·2	38·3	4·7	31·6	3·9
pAMPK/AMPK, pACC/ACC, SREBP-1, FAS and CPT-1 protein expression	Data represented by chart											
BW/body composition (mg/100 g BW)												
Final body weight (g)	202·4	9·2	249·4	8·3	230·6	7·2	216·9	8·1	207·5	6·4	206·2	7·3
Epididymal WAT	302	18·7	441	21·4	425	17·8	378	20·6	316	22·6	305	20·3
Perirenal WAT	202	16·1	279	18·3	253	17·9	222	20·4	216	18·4	212	20·2
Mesenteric WAT	151	10·1	209	12·3	190	14·9	175	8·9	162	9·1	155	11·4
Inguinal WAT	171	11·6	238	10·7	215	12·3	183	10·9	177	11·2	171	12·3

Table 2. *Continued*

Cicer arietium/Lens culinaris

Boualga *et al.*[61]	Groups					
	CAS (*n* 6)		CP (*n* 6)		L (*n* 6)	
	Mean	SEM	Mean	SEM	Mean	SEM
Lipid metabolism						
Plasma TAG (mmol/l)	0·99	0·23	0·53	0·13	0·42	0·19
Liver TC (μmol/g)	19·31	2·27	13·25	1·95	10·96	2·41
Liver TAG (μmol/g)	18·41	1·68	12·67	3·41	9·20	2·55
Hepatic lipase and lipoprotein lipase activity			Data represented by chart			
BW/body composition						
Body weight (g)	229·4	29·3	189·8	7·6	175·4	9·2
Weight gain (g/d per rat)	5·62	1·40	3·80	0·90	3·30	1·01
Epididymal fat weight (g/kg BW)	20·19	2·70	16·70	0·37	16·40	0·29

Pterocarpus santaniloides

Okwuosa *et al.*[53]	Groups											
	Positive CT (n 5)		AEPS 200 mg (n 5)		AEPS 400 mg (n 5)		MEPS 200 mg (n 5)		MEPS 400 mg (n 5)		Normal CT (n 5)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism												
Blood glucose (mg/dl)	194·50	9·87	108·75	26·21	76·75	6·25	72·25	10·99	138·00	15·25	64·00	3·44
Lipid metabolism												
Plasma TAG (mg/dl)	268·75	21·54	167·50	17·38	141·25	21·44	116·25	19·29	238·75	27·94	100·00	15·54

Pueraria lobata

Peng *et al.*[54]	Groups							
	Intact CT (*n* 7)		Intact kudzu (*n* 7)		Ovex CT (*n* 7)		Ovex kudzu (*n* 7)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Glucose metabolism								
Plasma glucose (mg/dl)	Data represented by chart							
Plasma insulin (ng/ml)	Data represented by chart							
Lipid metabolism								
Plasma TC (mg/dl)	Data represented by chart							
Blood pressure								
Arterial pressure (mmHg)	182	2	170	3	199	3	181	4

Tamarindus indica

Shahraki *et al.*[55]	Groups					
	CT		F		FT	
	Mean	SEM	Mean	SEM	Mean	SEM
Lipid metabolism						
TAG (mmol/l)	1·08	0·83	2·12	0·11	1·25	0·09
TC (mmol/l)	1·97	0·07	2·63	0·11	2·02	0·09
LDL (mmol/l)	0·52	0·05	0·98	0·13	0·64	0·05
VLDL (mmol/l)	0·49	0·04	0·97	0·05	0·57	0·03
HDL (mmol/l)	0·95	0·06	0·67	0·03	0·91	0·05
BW/body composition						
Body weight (g)	Data represented by chart. No exact numeric data available					

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Table 2. *Continued*

Tephrosia purpurea

Pavana *et al.*[57]	Groups									
	CT (n 6)		Diabetic CT (n 6)		Diabetic + TpALet (n 6)		CT + TpALet (n 6)		Diabetic + GLIB (n 6)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Glucose metabolism										
Blood glucose (mg/dl)	92·6	5·74	285·3	12·8	128·4	6·78	87·5	4·72	112·6	9·2
Plasma insulin (μU/ml)	16·1	0·81	10·6	0·87	14·1	1·03	16·6	0·98	14·7	1·08
Lipid metabolism										
TC (mg/dl)	80·16	6·5	150·83	8·6	120·9	7·3	78·7	5·3	114·6	7·5
Phospholipids (mg/dl)	93·2	6·99	146·3	9·83	116·6	8·16	91·3	7·75	107·5	9·35
TAG (mg/dl)	75·5	6·04	141·6	8·16	114·2	9·72	73·25	7·84	108·5	9·35
NEFA (mg/dl)	9·15	0·57	16·8	0·86	10·6	1·08	9·08	0·61	9·96	0·84
HDL-cholesterol (mg/dl)	35·33	1·47	21·64	0·73	28·36	1·08	36·08	1·35	29·1	0·94
LDL-cholesterol (mg/dl)	59·8	6·14	157·5	8·86	115·41	7·94	56·31	6·6	108·1	6·4
VLDL-cholesterol (mg/dl)	15·2	1·2	28·3	1·6	22·8	1·9	14·6	1·5	21·5	1·8
Liver TC (mg/g)	4·05	0·37	8·46	0·59	6·16	0·35	3·98	0·31	6·2	0·44
Liver TAG (mg/g)	3·89	0·25	6·54	0·47	4·96	0·20	3·86	0·29	4·61	0·27
Liver phospholipids (mg/g)	26·6	1·7	42·1	2·89	36·3	1·63	19·2	1·78	32·83	1·42
Liver NEFA (mg/g)	7·58	1·24	14·5	2·13	11·4	1·31	7·25	0·93	10·95	1·39

BR, bibliographic reference; CT, control diet; SBO, soyabean oil; LLO, low *α*-linolenic soyabean oil; F-diet, fructose diet; F-PL, 60 % fructose diet + phospholipids from soyabeans; G6PDX, glucose-6-phosphate dehydrogenase; TC, total cholesterol; FASN, fatty acid synthase; ACACA, acetyl-Coenzyme A carboxylase alpha; SCD1, stearoyl-CoA desaturase-1; CCD, starch and casein; FCD, fructose and casein; FSD, fructose and soya protein; CSD, starch and soya protein; HOMA-IR, homoeostatic model assessment for insulin resistance; ACE, angiotensin-converting enzyme; TBARs, thiobartituric acid-reactive substances; CAS, casein; SPI+, soya protein isolate; SPI–, soya protein isolate (negligible levels of phytochemicals); ACO, acyl-CoA oxidase; CPT-1, carnitine palmitoyltransferase I; HADHA, hydroxyacyl-CoA dehydrogenase/3-ketoacyl-CoA thiolase/enoyl-CoA hydratase; PPAR, peroxisome proliferator-activated receptors; CYP/A-1, cholesterol 7 alpha – hydroxylase; ABCG5, 8, ATP-binding cassette sub-family G members 5, 8; LXRα, liver X receptor alpha; EW, protein of egg white; SP, soya protein; fa/fa, obese phenotype; BW, body weight; 6-Keto PGF1α, 6-keto prostaglandin F1*α*; LIS, low isoflavone soya protein; HIS, high isoflavone soya protein; CR, casein + rosiglitazone; Co, cocoa; S, soya; O, oats; Ω, fish oil, ASM, after metabolic syndrome; BSM, before metabolic syndrome; STD, standard diet; HFS, high-fat high-sucrose diet; Fen, fenugreek group; CON, starch diet; FRU, high-fructose diet; FRU + FPEt, high-fructose diet with fenugreek seed polyphenolic extract (200 mg/kg); FRU + Quer, high-fructose diet with quercetin (50 mg/kg); FRU + Met, high-fructose diet with metformin (50 mg/kg); QUICKY, quantitative insulin sensitivity check index; $ISI_{0,120}$, insulin sensitivity index at 0 and 120 min; GP, glycogen phosphorylase; Glu, glucose; ICDH, isocitrate dehydrogenase; SDH, succinate dehydrogenase; PTP, protein tyrosine phosphatases; PTK, protein tyrosine kinases; FSP, fenugreek seed powder; Allx, alloxan; CHOL, cholesterol; ALAT, alanine transaminase; ASAT, aspartate transaminase; ALP, alkaline phosphatase; GAL, galactomannan; NC, normal CT; Or, orlistat; MCC-PS, microcrystalline cellulose-potato starch; H, hyperlipidaemic; HMCC-PS, hyperlipidaemic diet and composite of MCC-PS; C, control; A, control + 1 % adzuki bean; CF, high-fat diet; AF, high-fat diet +1 % adzuki bean; EtEx, ethanol extract of adzuki beans; PF, yellow pea fibre; PFL, yellow pea flour; PS, yellow pea starch; OFS, oligofructose; SREBP-1c, sterol regulatory element binding protein 1; ACC, acetyl-CoA carboxylase; WPF, whole pea flour; FPF, fractionated pea flour; LFO, licoride flavonoid oil; ND, normal diet; HFD, high-fat diet; LDP, low-dose pigeon pea; MDP, medium dose; HDP, high dose; PC, post-control; LDLr, LDL receptor; HMG-CoA, HMG-CoA reductase (3-hydroxy-3-methyl-glutaryl-CoA reductase); MDA, malondialdehyde; RCD, regular chow diet; HFD, high-fat diet; CSEE, *Casia* seed ethanol extract; PG, pioglitazone; AMPK, adenosine monophosphate protein kinase; WAT, white adipose tissue; CP, chickpea; L, lentils; AEPS, aqueous extract of *P. santaniloides*; MEPS, metanolic extract of *P. santaniloides*; Ovex, ovariectomised; F, fructose-fed rats; F-T, fructose-fed *Tamarindus indica* seed aqueous extract; TpALet, aqueous extract of *Tephrosia purpurea* leaves.

* References number[20,25,30,35,31,39,37,45,46,48,56,60]: no exact numeric data available, data represented by charts or figures.

† μmol of glucose phosphorylated/h per mg protein.

‡ μmol of pyruvate formed/min per mg protein.

§ μg of Pi liberated/min per protein.

‖ μmol of Pi liberates/h per protein.

¶ Total cholesterol:HDL-cholesterol ratio.

** LDL-cholesterol:HDL-cholesterol ratio.

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The interobserver raw agreement was calculated at 95·12 % ($k = 0·725$).

Mainly, as observed from the present review, the majority of the experiments were carried out using rats as an experimental model (*n* 30), followed by those that used mice (*n* 6). Focusing on the studies that used rats as the experimental model, different strategies for the induction and study of the MetS can be observed. Among them, the most common one is the induction of this pathology by diet in Wistar rats (*n* 15) followed by its induction on Sprague–Dawley (*n* 7) rats, another animal model that has been proven to be adequate for the study of this pathology. The most commonly used legume was *Glycine max* or soyabean (*n* 11), followed by *Trigonella foenum gracecum* or fenugreek (*n* 8) and *Phaseolus vulgaris* or beans (*n* 4), whereas in the rest of the studies a variety of legumes was used. The most common form of legume administration was in the form of an extract (*n* 11) or protein/fibre flour (*n* 7). It is worth mentioning that besides the study of the principal factors involved in the development of the MetS, the research is focused on the effects of the legume administration on the expression of several genes related to lipid, glucose and energy metabolism, as well as peptides and hormones associated with food intake, inflammatory markers and antioxidant status.

Glycine max/*soyabean*

Among the studies that used *Glycine max* as part of the diet intervention, one of them[17] studied the effects of soyabean protein administration on pups of pregnant rats. The results of this study point out lower body weight and lipoprotein expression of the hepatic lipoprotein cytochrome P450, subfamily 2, polypeptide 11 in the pups that consumed soya protein isolate. In addition, the specific intervention positively influenced genes involved in peroxisomal and mitochondrial fatty acid β-oxidation such as acyl-CoA oxidase (*COA*), the mitochondrial trifunctional protein α subunit (hydroxyacyl-CoA dehydrogenase/3-ketoacyl-CoA thiolase/enoyl-CoA hydratase) and fatty acid transport into the mitochondria by carnitine palmitoyltransferase 1A (*CPT-1A*) by increasing their expression in the liver. Further improvements on hepatic and serum lipid metabolism parameters due to soyabean administration were described in other studies[18–23]. Specifically, among the mentioned studies, Barrios-Ramos *et al.*[18] and Potu *et al.*[21] indicated that the administration of powder and oil of soyabean induced improvements on hepatic steatosis and the hepatic inflammation marker c-reactive protein, respectively. In addition, proteins involved in lipid synthesis pathways (fatty acid synthase (FAS), acetyl-coenzyme A carboxylase α, Stearoyl-CoA desaturase-1, fatty acid elongase 6, sterol regulatory element binding protein 1 (SREBP1) and carbohydrate-responsive element-binding protein) were down-regulated as a consequence of soyabean administration, thus suggesting an improvement in lipid metabolism pathways[19,24].

Regarding glucose metabolism, the majority of the studies suggest a clear improvement induced by the specific legume. A decrease in plasma glucose, leptin and insulin concentration, as well as an improvement in insulin sensitivity index[17,18,20,24,25], has been reported. Such a beneficial action of soyabean is further supported by increased expression of key enzymes and genes linked to glucose metabolism such as insulin I (INS1), insulin II (INS2), GLUT2[20] and PPARα and PPARγ[17,23,24] in pancreas, liver, muscle and adipose tissue.

Two of the retrieved studies pointed out positive effects of *Glycine max* on blood pressure[18,26], whereas Hwang *et al.*[27] observed a decrease of renal glomerular size and the improvement in parameters associated with glomerular filtration in the groups of rats fed soya protein. In this regard, Davis *et al.*[24] and Palanisamy *et al.*[26] reported a lower kidney weight, urinary volume and creatinine concentration, as well as proteinuria, because of the administration of this legume in Zucker diabetic and Wistar rats with MetS, respectively. Regarding oxidative stress in this tissue, the levels of thiobarbituric acid-reactive substances (TBARS) and GSH were restored and brought back to normal levels after the administration of *Glycine max*[26].

The study of Zhou *et al.*[25] focused on the effects of this legume on white adipose tissue, demonstrating a decrease of the weight of this tissue in male and female mice.

Trigonella foenum gracecum/*fenugreek*

The use of fenugreek in all its different forms – that is, seed powder[28,29], extract[30–32] isolated polyphenols[33] or polysaccharide galactomannan[34,35] – points out to the beneficial changes in glucose metabolism, as demonstrated by lower levels of blood insulin, glucose, AUC, as well as higher homoeostatic model assessment for insulin resistance (HOMA-IR) index. Moreover, the re-establishment of the enzymes that play an integral role within the insulin signalling cascade back to normal levels highlights this potential action[33]. Specifically, Srichamroen *et al.*[35] demonstrated that galactomannan of fenugreek reveals its function at the intestinal level by reducing the *in vitro* uptake of glucose in both jejunum and ileal segments. Moreover, the hypolipidaemic properties of fenugreek are clearly demonstrated by lower levels of lipid fractions in blood[28–31,34] and TAG in epididymal adipose tissue[34], the weight of the latter being significantly lower after combining high-fat diets with powder of fenugreek seeds[28]. Liver function markers such as alanine transaminase (ALT), aspartate transaminase (AST) and alkaline phosphatase activities[29,31], concentration of TBARS, as well as the activities of antioxidant enzymes such as catalase and superoxide dismutase[25], decreased because of the administration of this legume. In addition, serum parameters of renal functionality such as urea, uric acid and creatinine were reduced by fenugreek extract administration[31]. Regarding the action of the specific legume on the immune system, Ramadan *et al.*[29] investigated the effects of fenugreek seed powder using an immunosuppressive rat model and demonstrated its potential by decreasing abnormalities of the immune system such as leucopenia, neutropenia and lymphopenia while increasing spleen-weight:body weight ratio and cellularity of lymphoid organs.

Phaseolus vulgaris/*beans*

The administration of *P. vulgaris* revealed a decrease in daily food intake and body weight, as well as improvements in plasma lipid parameters such as total cholesterol (TC), TAG, phospholipids and phosphorus phospholipids[36–38]. Moreover, bean consumption caused a decrease in acetyl-CoA carboxylase (ACC) and increments in cholesterol 7 α-hydroxylase levels[38]. Specifically, the study of Zaru *et al.*[39] demonstrated a decrease in the seeking behaviour of chocolate-flavoured beverage of animals fed *P. vulgaris* extracts compared with the animals in the control group. Regarding plasma glucose metabolism parameters, only blood glucose, plasma leptin and AUC were determined, which were all lower after the administration of this legume[36,37].

Vigna angularis/*adzuki beans*

In the three studies retrieved[40–42], the dietary intervention with *Vigna angularis*/Adzuki beans included the administration of this legume as an extract. The studies focused on glucose and lipid metabolism, indicating a reduction in glucose, insulin, glycated Hb and microalbumin:creatinine ratio in the plasma of the animals. In addition, concentrations of TC, TAG, as well as lipid content of the liver, were reduced as a consequence of the administration of this legume. Similar reductions were produced in liver weight. In contrast, faecal weight and lipid excretion were found to be increased.

Pissum sativum/*yellow pea*

The two studies retrieved[43,44] demonstrated a reduction in blood glucose and insulin concentrations due to yellow pea administration, as well as decreased hepatic TAG, decreased ACC and increased SREBP mRNA levels.

Astragalus membranaceus/*huáng-Qí (translated as yellow leader)*

The two studies retrieved[45,46] used male diabetic animal models and aimed to study the effects of this legume on parameters related to glucose and lipid metabolism. Body weight was reduced resulting from legume administration, as well as parameters such as serum glucose and insulin concentrations, AUC and HOMA-IR index. In contrast, glucose infusion rate, after the performance of a hyperglycaemic clamp test, and hepatic glycogen content increased. Similar improvements were also found in parameters of lipid and energy metabolism represented by reduction of plasma TC and fatty acid concentration, as well as ACC and adenosine monophosphate activated protein (pAMPK) expression in the liver. The study of Gao *et al.*[45] performed histology and immunohistochemistry analyses of pancreas, demonstrating reduced pathological changes, stain intensity and area in the groups administered with the legume. Inflammation markers studied by Hoo *et al.*[46] were reduced in the adipose tissue of the treated groups.

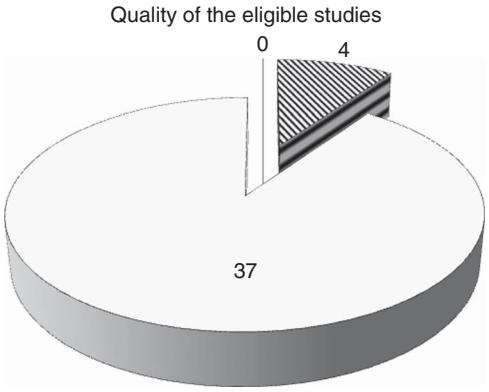

Fig. 2. Quality of the included studies of the systematic review. ▨, Excellent; □, good; ■, bad.

Glycyrrhiza glabra/*liquorice*

The administration of *Glycyrrhiza glabra* lowered blood glucose, HOMA-IR index, serum insulin and leptin levels[47,48]. Moreover, the 18-week administration of liquorice flavonoid oil (LFO) (1 %) led to lower body weight and periuterine and white adipose tissue of female C7BL/6J mice, whereas LFO (2 %) decreased adipocyte diameter and number of lipid droplets. In addition, it caused the up-regulation of genes related to β-oxidation and acyl-CoA degradation and down-regulation of glycolytic lipogenesis genes and those associated with acetyl-CoA synthesis[47]. Increases in PPARγ and lipoprotein lipase (LPL) relative expressions after the administration of *G. glabra* were reported by the study of Yoke *et al.*[48].

Other legumes

Other legumes in addition to the previously described ones have shown different effects on parameters associated with the MetS. The administration of amorfrutins of *Glycyrrhiza foetida* and *Amorpha fruticosa* (false indigo[49]), *Cajanus cajan* (pigeon pea) powder, *Pterocarpus santaniloides* (Mututi[49]) leaf extract, *Pueraria lobata* (Kudzu[50]) root extract and *Tamarindus indica* (tamarind tree[51]) aqueous extract[52–56] decreased blood glucose, insulin content, as well as glucose and insulin AUC. The above-mentioned legumes in addition to *Tephrosia purpurea*, *Amorpha* administrated as a leaf extract[57] have also shown their beneficial effect on parameters of lipid metabolism by lowering the serum levels of different lipid fractions. Tzeng *et al.*[58] demonstrated that an ethanol extract of *Cassia tora* (Foetid cassia[59]) reduced the size of white adipose tissue, as well as the expression of enzymes such as FAS and SREBP in this tissue. In addition, it up-regulated the expression pAMPK, pACC and CPT1, all enzymes related to energy metabolism, and improved parameters of cardiovascular function such as atherogenic index and coronary risk index. Focusing on hepatic lipid metabolism, legumes such as *Aspalathus linearis* (Roibos), *Lens culinaris* (Lentils), *C. cajan*, *G. foetida* and *T. purpurea*[52,56,60] improved liver functionality by reducing liver weight, hepatic cholesterol and TAG content in addition to the reduction of lipid droplet accumulation and

expression of TNFα, a widely used inflammation marker. According to the results of the present systematic review, only one study by Peng *et al.*[54] pointed out the beneficial effects on blood pressure after the inclusion of the root extract of *P. lobata* in the diet of the pups of an animal model of spontaneously hypertensive rats.

Discussion

The present systematic review was undertaken to give a comprehensive overview of the benefits of legume consumption on parameters related to the MetS and collect the existent mechanisms of action so far reported in animal experimental trials. In addition, it aimed to identify scarcities or abundancies with respect to legume consumption and its potential beneficial influence on the MetS alterations.

After the screening of the papers, data of forty-one studies were extracted. To our knowledge, this is the first systematic review gathering together the beneficial effects that a wide variety of legumes, most of them of common use, exert on the MetS, and include data on the way that legumes affect specific metabolic pathways involved in this pathology. The mechanistic emphasis of this review implies that preferentially animal studies were chosen.

Although some studies in humans indicate possible undesired effects due to the consumption of legumes, no such effects were reported in the studies collected for this review. Moreover, no toxicity effects by the administration of legumes in any form were reported. However, an increase of hepatic phospholipids was induced by the administration of adzuki beans[41], chickpeas and lentils[61], in addition to a decrease of LPL activity in epididymal fat reported by the latter study. In addition, in the study of Shahraki *et al.*[55], an elevation of AST and ALT was observed in the group that consumed the aqueous extract of *T. indica*. As for the insulin resistance, Wagner *et al.*[23] concluded that after soya isoflavone administration, insulin responses significantly increased and were accompanied by decreased plasma adiponectin concentrations. In a similar manner, administration of soyabean oil in Ossabaw pigs[21] resulted in elevated concentrations of glucose and insulin concentrations in plasma, as well as elevated blood lipids. Nevertheless, despite the negative effects of legume consumption in the above-mentioned studies, the majority of the studies gathered by the present systematic review highlight the beneficial effects of legume administration on the development and progression of the MetS and its related pathologies.

According to the results of the CACEC-EC questionnaire, the quality of the retrieved studies was good (Fig. 2), although there was great heterogeneity among them. In addition to the variety of legumes used, they were administered in different forms such as seed powder, extract or different fractions of the legume (protein, fibre). There was also great heterogeneity regarding the experimental period of the studies finally selected, which varied from 2 h[32] to 40 weeks[23]. However, all of them were randomised intervention studies according to the inclusion criteria established.

The frequent use of *Glycine max*/soyabean in the studies retrieved can be explained because of the declaration of its protein as a good substitute for animal products, offering a 'complete' protein profile and its protective action against CVD[62,63] by the US Food and Drug Administration[64]. Most of the studies included the investigation of various metabolic parameters simultaneously trying to offer evidence on more than one metabolic pathway. The most widely mentioned parameters related to glucose, lipid and renal metabolism are included, whereas inflammation, oxidative status, blood pressure, body weight and body composition were studied in fewer studies. Only one study focused on the anorectic effects of legumes by reducing appetite and craving for food[39].

As impairments of glucose metabolism are directly related to the MetS, these alterations are widely studied. Therefore, lowering glucose concentration, HOMA-IR index or increasing insulin response are among the most reported findings. Such positive effects seem to be independent from the intervention duration, as even the shortest intervention[32] induced an improvement in blood glucose. However, it is worth mentioning that in this study *T. foenum graecum* extract was directly injected in alloxan-induced diabetic animals. In general, twenty-nine of the retrieved studies showed improvements in glucose metabolism and included several legumes such as *Glycine max*[17–20,24,26,38], *T. foenum graecum*[28,29,31–33], *P. vulgaris*[36–38], *V. angularis*[41], *Pisum sativum*[43,44], *Astragalus membranaceus*[45,46], *G. glabra*[47,48], *C. cajan*[52], *G. foetida* and *A. fruticosa*[56], *P. santaniloides*[53], *P. lobata*[54], *T. indica*[55] and *T. purpurea*[57]. No such effects were reported for *A. linearis*[60], *C. tora*[58] and *L. culinaris*/*Cicer arietinum*[61]. It seems that legumes influence the mechanistic pathways involving the expression of genes related to glucose metabolism such as GLUT2, GLUT4, INS1 or INS2[20,24], although the expression of more genes need to be studied. One of the retrieved studies also measured the activities of glucose- and glycogen-metabolising enzymes, therefore demonstrating the beneficial effect that polyphenols of *T. foenum graecum* exert on glucose metabolic pathways[33]. Moreover, the study of Srichamroen *et al.*[35] revealed that another possible mechanism explaining glucose regulation is possible through the action of a galactomannan of the same legume in the reduction of the uptake of glucose by jejunum and ileal segments of the intestine.

In a manner similar to glucose metabolism, lipid parameters seem to be positively influenced by the administration of all sixteen different legumes that have been included in this review. Among the most widely mentioned beneficial improvements, the reduction of different lipid fractions in plasma, such as total-, LDL-, HDL-cholesterol and TAG[20,22,28–31,34,36,38,46,48,54–56,58,61], hepatic TAG and phospholipid content[17,19,60], or both of them[18,24,40–43,45,52,61], is reported. Other improvements associated with lipid metabolism and body composition are the decrease of body fat mass and white adipose tissue by *Glycine max*[17,25], as well as the reduction of hepatic steatosis induced by this same legume[18]. In this regard, the administration of *G. glabra* and *A. linearis* also reduced the number of lipid droplets in the liver[47,60]. Moreover, the studies of Aoki *et al.*[47] and Tzeng *et al.*[58] used

the determination of mesenteric, perirenal, periuterine, inguinal and epididymal fat as a marker of increased lipid adiposity in animals and further improvement of this parameter by the administration of *G. glabra* and *C. tora*, respectively. It is quite clear that the MetS is related to impaired fat excretion, whereas the administration of *V. angularis* extract[42] and *Pigeon pea*[52] improves such alteration. The results of the collected studies demonstrate that a great number of genes related to *β*-oxidation and acyl-CoA degradation are up-regulated by the administration of several legumes, whereas glycolytic lipogenesis genes are down-regulated. In particular, *Glycine max*[17,19,23,24], *P. vulgaris*[38], *P. sativum*[43], *A. membranaceus*[45], *G. glabra*[47,48], *C. cajan*[52], *C. tora*[58], *G. foetida/A. fructicosa*[56] are among the encountered legumes with such action. Still, collected data indicate that more research needs to be developed on these and other potential mechanism related to the beneficial influence of legumes on lipid metabolism, whereas a greater range of legume species needs to be tested.

It is well known that renal alterations can occur with the development of the MetS. However, as demonstrated by the results of this systematic review, only six of the collected studies mention beneficial results on renal metabolism in which only four different legumes are included: *Glycine max*[24,26,27], *T. foenum graecum*[31], *V. angularis*[41] and *C. cajan*[52]. In this regard, legume administration managed to restore the augmented kidney weight, urea level, uric acid and creatinine derived from the administration of a high-fructose diet. The presence of glucose and protein in urine are also linked to alterations of renal metabolism and were improved by the administration of *V. angularis*[41] and *Glycine max*[24]. Worth mentioning is the study by Palanisamy *et al.*[26] that described a simultaneous reduction of blood pressure together with concomitant improvements in renal metabolism, as soya protein reduced glucose levels and produced the inhibition of the angiotensin-converting enzyme. Still, there is a lack of information in this field for the majority of the legumes gathered by this review.

The process of inflammation is highly involved in the development of the MetS and can be determined by the concentration of oxidative markers or the activity of antioxidant enzymes in different organs. As observed by this systematic review, only five of the legumes collected have been so far used to investigate these parameters. Among them, *Glycine max*[21,26], *T. foenum graceum*[29,30], *A. membranaceus*[46], *C. cajan*[52] and *Glythirrhiza foetida/A. fructicosa*[56] are encountered. Two clear tendencies are observed for the evaluation of these parameters: on the one hand, the simultaneous determination of oxidative damage, as well as antioxidant enzymes[26,30,52], and on the other hand[29,46,56], the study of the level of cytokines involved in the process of inflammation.

Overall, legume administration positively affects glucose and lipid metabolism, which include the most widely studied parameters. Fewer studies have been focused in renal metabolism and the properties of legumes as antioxidant and anti-inflammatory agents. A possible limitation of the present review is that the bibliographic search was carried out based on the definition of search terms through the use of MeSH, not followed by all studies. It is important that the same rules be followed for the establishment of key words so that the inclusion of all available studies would be ensured.

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References

1. Anderson PJ, Critchley JAJH, Chan JCN, *et al.* (2001) Factor analysis of the metabolic syndrome: obesity vs insulin resistance as the central abnormality. *Int J Obes Relat Metab Disord* **25**, 1782–1788.
2. Indulekha K, Surendar J & Mohan V (2011) High sensitivity C-reactive protein, tumor necrosis factor-*α*, interleukin-6, and vascular cell adhesion molecule-1 levels in Asian Indians with metabolic syndrome and insulin resistance (CURES-105). *J Diabetes Sci Technol* **5**, 982–988.
3. International Diabetes Federation (2006) IDF worldwide definition of the metabolic syndrome. http://www.idf.org/metabolic-syndrome (accessed October 2014).
4. Reaven GM (1988) Role of insulin resistance in human disease. *Diabetes* **37**, 1595–1607.
5. Alberti K, Zimmet P & Shaw J (2006) Metabolic syndrome – a new world-wide definition. A Consensus Statement from the International Diabetes Federation. *Diabet Med* **23**, 469–480.
6. Kaur J (2014) A comprehensive review on metabolic syndrome. *Cardiol Res Pract* **2014**, e943162.
7. Manco M, Bottazzo G, DeVito R, *et al.* (2008) Nonalcoholic fatty liver disease in children. *J Am Coll Nutr* **27**, 667–676.
8. Deen D (2004) Metabolic syndrome: time for action. *Am Fam Physician* **69**, 2875–2882.
9. Duranti M (2006) Grain legume proteins and nutraceutical properties. *Fitoterapia* **77**, 67–82.
10. König D, Muser K, Berg A, *et al.* (2012) Fuel selection and appetite-regulating hormones after intake of a soy protein-based meal replacement. *Nutrition* **28**, 35–39.
11. Segura Campos MR, Chel Guerrero LA & Betancur Ancona DA (2010) Angiotensin-I converting enzyme inhibitory and anti-oxidant activities of peptide fractions extracted by ultrafiltration of cowpea *Vigna unguiculata* hydrolysates. *J Sci Food Agric* **90**, 2512–2518.
12. Yoshie-Stark Y & Wäsche A (2004) *In vitro* binding of bile acids by lupin protein isolates and their hydrolysates. *Food Chem* **88**, 179–184.

13. Tomás-Casterá V, Sanz-Valero J & Juan-Quilis V (2013) [Bibliometric analysis of the scientific production and consumption on nutrition journals indexed in scielo network]. *Nutr Hosp* **28**, 969–970.
14. Burton RE & Kebler RW (1960) The 'half-life' of some scientific and technical literatures. *Am Doc* **11**, 18–22.
15. Cohen J (1968) Weighted kappa: nominal scale agreement provision for scaled disagreement or partial credit. *Psychol Bull* **70**, 213–220.
16. Wanden-Berghe C & Sanz-Valero J (2012) Systematic reviews in nutrition: standardized methodology. *Br J Nutr* **107**, S3–S7.
17. Ronis MJ, Chen Y, Badeaux J, *et al.* (2009) Dietary soy protein isolate attenuates metabolic syndrome in rats via effects on PPAR, LXR, and SREBP signaling. *J Nutr* **139**, 1431–1438.
18. Barrios-Ramos JP, Garduño-Siciliano L, Loredo M, *et al.* (2012) The effect of cocoa, soy, oats and fish oil on metabolic syndrome in rats. *J Sci Food Agric* **92**, 2349–2357.
19. Mori T, Kondo H, Hase T, *et al.* (2011) Dietary phospholipids ameliorate fructose-induced hepatic lipid and metabolic abnormalities in rats. *J Nutr* **141**, 2003–2009.
20. Nordentoft I, Jeppesen PB, Hong J, *et al.* (2008) Increased insulin sensitivity and changes in the expression profile of key insulin regulatory genes and beta cell transcription factors in diabetic KKAy-mice after feeding with a soy bean protein rich diet high in isoflavone content. *J Agric Food Chem* **56**, 4377–4385.
21. Potu RB, Lu H, Adeola O, *et al.* (2013) Metabolic markers in Ossabaw pigs fed high fat diets enriched in regular or low α-linolenic acid soy oil. *Nutr Metab* **10**, 27.
22. Torre-Villalvazo I, Tovar AR, Ramos-Barragán VE, *et al.* (2008) Soy protein ameliorates metabolic abnormalities in liver and adipose tissue of rats fed a high fat diet. *J Nutr* **138**, 462–468.
23. Wagner JD, Zhang L, Shadoan MK, *et al.* (2008) Effects of soy protein and isoflavones on insulin resistance and adiponectin in male monkeys. *Metabolism* **57**, Suppl. 1, S24–S31.
24. Davis J, Higginbotham A, O'Connor T, *et al.* (2007) Soy protein and isoflavones influence adiposity and development of metabolic syndrome in the obese male ZDF rat. *Ann Nutr Metab* **51**, 42–52.
25. Zhou J-R, Li L & Pan W (2007) Dietary soy and tea combinations for prevention of breast and prostate cancers by targeting metabolic syndrome elements in mice. *Am J Clin Nutr* **86**, s882–s888.
26. Palanisamy N, Viswanathan P, Ravichandran MK, *et al.* (2010) Renoprotective and blood pressure-lowering effect of dietary soy protein via protein kinase C βII inhibition in a rat model of metabolic syndrome. *Can J Physiol Pharmacol* **88**, 28–37.
27. Hwang S-Y, Taylor CG, Zahradka P, *et al.* (2008) Dietary soy protein reduces early renal disease progression and alters prostanoid production in obese fa/fa Zucker rats. *J Nutr Biochem* **19**, 255–262.
28. Muraki E, Chiba H, Tsunoda N, *et al.* (2011) Fenugreek improves diet-induced metabolic disorders in rats. *Horm Metab Res* **43**, 950–955.
29. Ramadan G, El-Beih NM & Abd El-Kareem HF (2011) Anti-metabolic syndrome and immunostimulant activities of Egyptian fenugreek seeds in diabetic/obese and immunosuppressive rat models. *Br J Nutr* **105**, 995–1004.
30. Belguith-Hadriche O, Bouaziz M, Jamoussi K, *et al.* (2010) Lipid-lowering and antioxidant effects of an ethyl acetate extract of fenugreek seeds in high-cholesterol-fed rats. *J Agric Food Chem* **58**, 2116–2122.
31. Eidi A, Eidi M & Sokhteh M (2007) Effect of fenugreek (*Trigonella foenum-graecum* L) seeds on serum parameters in normal and streptozotocin-induced diabetic rats. *Nutr Res* **27**, 728–733.
32. Mowla A, Alauddin M, Rahman MA, *et al.* (2009) Antihyperglycemic effect of *Trigonella foenum-graecum* (fenugreek) seed extract in alloxan-induced diabetic rats and its use in diabetes mellitus: a brief qualitative phytochemical and acute toxicity test on the extract. *Afr J Tradit Complement Altern Med* **6**, 255–261.
33. Kannappan S & Anuradha CV (2009) Insulin sensitizing actions of fenugreek seed polyphenols, quercetin & metformin in a rat model. *Indian J Med Res* **129**, 401–408.
34. Srichamroen A, Field CJ, Thomson ABR, *et al.* (2008) The modifying effects of galactomannan from Canadian-grown fenugreek (*Trigonella foenum-graecum* L.) on the glycemic and lipidemic status in rats. *J Clin Biochem Nutr* **43**, 167–174.
35. Srichamroen A, Thomson ABR, Field CJ, *et al.* (2009) *In vitro* intestinal glucose uptake is inhibited by galactomannan from Canadian fenugreek seed (*Trigonella foenum graecum* L) in genetically lean and obese rats. *Nutr Res* **29**, 49–54.
36. Adel AM & El-shinnawy NA (2012) Hypolipidemic applications of microcrystalline cellulose composite synthesized from different agricultural residues. *Int J Biol Macromol* **51**, 1091–1102.
37. Carai MAM, Fantini N, Loi B, *et al.* (2011) Multiple cycles of repeated treatments with a *Phaseolus vulgaris* dry extract reduce food intake and body weight in obese rats. *Br J Nutr* **106**, 762–768.
38. Zhu Z, Jiang W & Thompson HJ (2012) Edible dry bean consumption (*Phaseolus vulgaris* L.) modulates cardiovascular risk factors and diet-induced obesity in rats and mice. *Br J Nutr* **108**, Suppl. 1, S66–S73.
39. Zaru A, Maccioni P, Riva A, *et al.* (2013) Reducing effect of a combination of *Phaseolus vulgaris* and *Cynara scolymus* extracts on operant self-administration of a chocolate-flavoured beverage in rats. *Phytother Res PTR* **27**, 944–947.
40. Itoh T & Furuichi Y (2009) Lowering serum cholesterol level by feeding a 40% ethanol-eluted fraction from HP-20 resin treated with hot water extract of adzuki beans (*Vigna angularis*) to rats fed a high-fat cholesterol diet. *Nutrition* **25**, 318–321.
41. Itoh T, Kobayashi M, Horio F, *et al.* (2009) Hypoglycemic effect of hot-water extract of adzuki (*Vigna angularis*) in spontaneously diabetic KK-A(y) mice. *Nutrition* **25**, 134–141.
42. Kitano-Okada T, Ito A, Koide A, *et al.* (2012) Anti-obesity role of adzuki bean extract containing polyphenols: *in vivo* and *in vitro* effects. *J Sci Food Agric* **92**, 2644–2651.
43. Eslinger AJ, Eller LK & Reimer RA (2014) Yellow pea fiber improves glycemia and reduces *Clostridium leptum* in diet-induced obese rats. *Nutr Res* **34**, 714–722.
44. Marinangeli CPF, Krause D, Harding SV, *et al.* (2011) Whole and fractionated yellow pea flours modulate insulin, glucose, oxygen consumption, and the caecal microbiome in Golden Syrian hamsters. *Appl Physiol Nutr Metab* **36**, 811–820.
45. Gao L, Liu Q, Liu S, *et al.* (2014) A refined-JinQi-JiangTang tablet ameliorates prediabetes by reducing insulin resistance and improving beta cell function in mice. *J Ethnopharmacol* **151**, 675–685.
46. Hoo RL, Wong JY, Qiao CF, *et al.* (2010) The effective fraction isolated from Radix Astragali alleviates glucose intolerance, insulin resistance and hypertriglyceridemia in db/db diabetic mice through its anti-inflammatory activity. *Nutr Metab* **7**, 67.
47. Aoki F, Honda S, Kishida H, *et al.* (2007) Suppression by licorice flavonoids of abdominal fat accumulation and body weight gain in high-fat diet-induced obese C57BL/6J mice. *Biosci Biotechnol Biochem* **71**, 206–214.
48. Yoke Yin C, So Ha T & Abdul Kadir K (2010) Effects of glycyrrhizic acid on peroxisome proliferator-activated receptor gamma (PPARgamma), lipoprotein lipase (LPL), serum lipid and HOMA-IR in rats. *PPAR Res* **2010**, 530265.

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49. International Legume Database & Information Service (2015) ILDIS home page. http://www.ildis.org/ (accessed March 2016).
50. Ulbricht C, Costa D, Dam C, *et al.* (2015) An evidence-based systematic review of Kudzu (*Pueraria lobata*) by the Natural Standard Research Collaboration. *J Diet Suppl* **12**, 36–104.
51. Kuru P (2014) *Tamarindus indica* and its health related effects. *Asian Pac J Trop Biomed* **4**, 676–681.
52. Dai F-J, Hsu W-H, Huang J-J, *et al.* (2013) Effect of pigeon pea (*Cajanus cajan* L.) on high-fat diet-induced hypercholesterolemia in hamsters. *Food Chem Toxicol* **53**, 384–391.
53. Okwuosa CN, Unekwe PC, Achukwu PU, *et al.* (2013) Glucose and triglyceride lowering activity of *Pterocarpus santaniloides* leaf extracts against dexamethasone induced hyperlipidemia and insulin resistance in rats. *Afr J Biotechnol* **10**, 9415–9420.
54. Peng N, Prasain JK, Dai Y, *et al.* (2009) Chronic dietary kudzu isoflavones improve components of metabolic syndrome in stroke-prone spontaneously hypertensive rats. *J Agric Food Chem* **57**, 7268–7273.
55. Shahraki MR, Harati M & Shahraki AR (2011) Prevention of high fructose-induced metabolic syndrome in male Wistar rats by aqueous extract of *Tamarindus indica* seed. *Acta Med Iran* **49**, 277–283.
56. Weidner C, de Groot JC, Prasad A, *et al.* (2012) Amorfrutins are potent antidiabetic dietary natural products. *Proc Natl Acad Sci* **109**, 7257–7262.
57. Pavana P, Manoharan S, Renju GL, *et al.* (2007) Antihyperglycemic and antihyperlipidemic effects of *Tephrosia purpurea* leaf extract in streptozotocin induced diabetic rats. *J Environ Biol* **28**, 833–837.
58. Tzeng T-F, Lu H-J, Liou S-S, *et al.* (2013) Reduction of lipid accumulation in white adipose tissues by *Cassia tora* (Leguminosae) seed extract is associated with AMPK activation. *Food Chem* **136**, 1086–1094.
59. Awasthi VK, Mahdi F, Chander R, *et al.* (2015) Hypolipidemic activity of *Cassia tora* seeds in hyperlipidemic rats. *Indian J Clin Biochem* **30**, 78–83.
60. Beltrán-Debón R, Rull A, Rodríguez-Sanabria F, *et al.* (2011) Continuous administration of polyphenols from aqueous rooibos (*Aspalathus linearis*) extract ameliorates dietary-induced metabolic disturbances in hyperlipidemic mice. *Phytomedicine* **18**, 414–424.
61. Boualga A, Prost J, Taleb-Senouci D, *et al.* (2009) Purified chickpea or lentil proteins impair VLDL metabolism and lipoprotein lipase activity in epididymal fat, but not in muscle, compared to casein, in growing rats. *Eur J Nutr* **48**, 162–169.
62. Sirtori CR, Gatti E, Mantero O, *et al.* (1979) Clinical experience with the soybean protein diet in the treatment of hypercholesterolemia. *Am J Clin Nutr* **32**, 1645–1658.
63. Descovich GC, Gaddi A, Mannino G, *et al.* (1980) Multicentre study of soybean protein diet for outpatient hypercholesterolaemic patients. *Lancet* **ii**, 709–712.
64. Sacks FM, Lichtenstein A, Horn LV, *et al.* (2006) Soy protein, isoflavones, and cardiovascular health: an American Heart Association Science Advisory for Professionals from the Nutrition Committee. *Circulation* **113**, 1034–1044.

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