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REVIEW ARTICLE

Herbal tea used globally targeting metabolic syndrome: A systematic review

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Abstract

Background Metabolic syndrome (MetSyn) is a cluster of metabolic constellations which includes hypertension, central obesity, insulin resistance and atherogenic dyslipidaemia. MetSyn is a group of interconnected risk factors linked to diabetes, cancer, stroke and other comorbidities. Herbal tea (HT) has been reported to play an important role in managing MetSyn. However, very few HTs are scientifically validated. This systematic review focuses on the reports of scientific validation of different HTs used globally to treat MetSyn.

Objective Our study emphasizes on all the clinical trial studies that utilize HTs targeting MetSyn globally, and additionally focuses on different preclinical studies involving HTs and their mechanism of action.

Methods This study was performed considering the guidelines of Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) and studies were screened out from various scientific databases like PubMed, Google Scholar, Web of Science, etc. considering inclusion and exclusion criteria.

Results A detailed analysis divulged 15 different clinical studies of herbal teas against MetSyn globally, regarding which studies were conducted between the years 1990 and 2023 by a total of 897 participants. Further investigation led to 31 different preclinical studies which in the form of infusion/decoction have been used to treat MetSyn. It was also revealed that mostly leaf parts were used in preparing the herbal tea. Additionally, Asia has reported the highest number of herbal teas followed by other continents; the most targeted MetSyn was diabetes. Various reported mechanisms of action have also been tabulated.

Conclusion Supplements from natural sources like herbal teas are good alternatives to conventional drugs for combating MetSyn. Although, the usage of herbal teas in the management of MetSyn is widespread; however, very few have been scientifically validated in a preclinical and clinical setup. In-depth studies are warranted to ascertain the clinical efficacy and safety of herbal teas.

Keywords Herbal tea · Infusion · Metabolic syndrome · Hypertension · Obesity · Dyslipidaemia

Introduction

With the decrease in the trend of communicable diseases, non-communicable diseases have gained momentum over the past three decades disrupting all the disease patterns [1]. Metabolic syndrome (MetSyn), also known as 'Syndrome X' or 'Insulin Resistance Syndrome' or 'Hypertriglyceridemic Waist' or 'The Deadly Quartet', is a cluster of metabolic constellations which includes hypertension, central obesity, insulin resistance and atherogenic dyslipidaemia. MetSyn includes increased waist circumference, fasting triglyceride, fasting blood sugar and increased blood sugar and decreased fasting high-density lipoprotein cholesterol level (Fig. 1).

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Both inherited and acquired variables that contribute to the ultimate inflammatory cascade resulting in CVD are involved in the aetiology of MetSyn. MetSyn is a group of interconnected risk factors linked to diabetes, cancer, stroke and other comorbidities. Obesity and type 2 diabetes are often associated with a higher incidence of MetSyn. Due to the worldwide exponential rise in obesity, MetSyn has recently become a topic of interest [2]. The worldwide occurrence of metabolic syndrome (MetS) ranged from 12.5 to 31.4% depending on how it was defined. An analysis carried out in South Asia found that the occurrence of metabolic syndrome (MetS) was 14.0% according to the World Health Organisation (WHO), 26.1% according to the Adult Treatment Panel III (ATP III), 29.8% according to the International Diabetes Federation (IDF) and 32.5% according to a modified version of ATP III [3]. Approximately, 20–25% of the global adult population is believed to have MetSyn. Individuals with this syndrome are twice as likely to experience mortality and three times as likely to suffer from a heart attack or stroke, in comparison to those without the condition [4].

Nature has bestowed us with numerous gifts. Various plants, herbs, shrubs, etc. have been used extensively to avoid and treat a variety of diseases for thousands of years because of their remarkable efficacy and minimal side effects [5]. With the advancement of science and technology, many plants that were used traditionally for treating various ailments have been scientifically validated, reducing the time for new drug discoveries [6]. HT is a novel dosage form that has emerged as a result of the rise in popularity of tea drinking and the gradual accumulation of medical practice experience. HT is made by processing certain herbs that have remarkable curative effects and immediately brewing them for consumption. HT may be single herbal or polyherbal. The natural components of various morphological plant sections, including leaves, stems, roots, fruits, buds and flowers, are used to make HTs in general. Natural bioactive substances like carotenoids, phenolic acids, flavonoids, coumarins, alkaloids, polyacetylenes, saponins and terpenoids, among others, are abundant in HTs [7]. Some HTs from plants like *Camellia sinensis*, *Gynostemma pentaphyllum*, etc. have significantly reduced body weight, body mass index, fasting blood glucose, etc. HTs from *Hibiscus sabdariffa* L. have been reported to have anti-hypertensive activity. This review summarizes all the clinical studies of HTs against MetSyn globally, also keeping the focus on tabulating the preclinical studies of HTs and their mechanism of action.

Methods

Study design

This systematic review focused on analysing different HTs used globally to treat MetSyn. This study was performed considering the guidelines of Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) which included both inclusion and exclusion criteria [8].

Data sources and search strategy

Methods to find pertinent articles for this study were established by keeping the main objective of the systematic review in observance. Various scientific databases like Google Scholar, PubMed and Scopus were searched to find

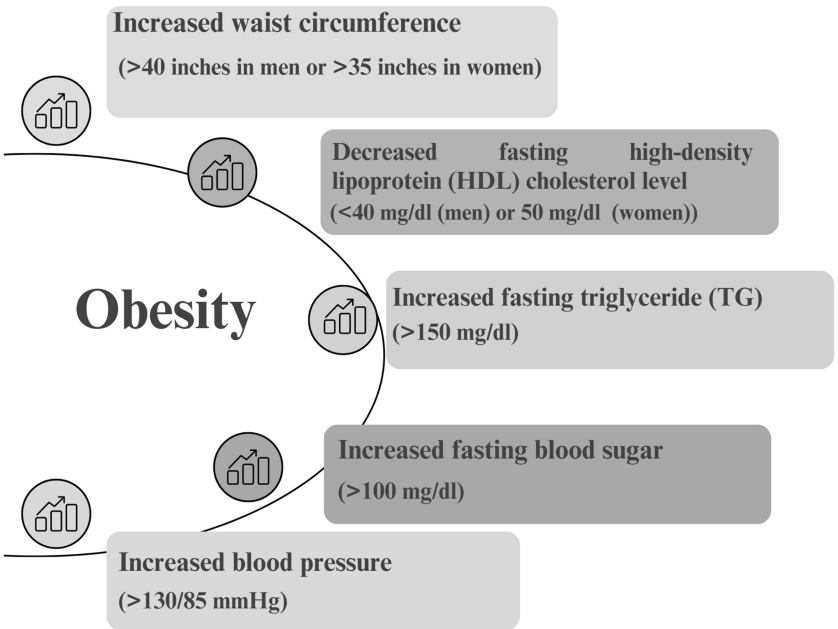

Fig. 1 Impact of metabolic syndrome

the relevant literature. The data search was last updated in March 2023.

Specific keyword combinations like "Metabolic syndrome" OR "Herbal Tea" OR "Decoction" OR "Infusion" OR "Infusion" OR "Obesity" OR "Diabetes" OR "Hypertension" OR "Clinical trial" as well as free-text words were used.

A further search was conducted to find records of herbal tea against MetSyn preclinically. Various keyword combinations such as "Metabolic syndrome" OR "Herbal Tea" OR "Decoction" OR "Infusion" OR "Obesity" OR "Diabetes" OR "Hypertension" as well as free-text words were used.

Inclusion and exclusion criteria

The review included journal articles that reported herbal tea in the treatment of MetSyn globally. The inclusion criteria of the articles are (1) full-length articles published in the English language only and (2) journal articles that reported potency of herbal tea against MetSyn globally.

Articles published in languages other than English, articles published in platforms/forums other than scientific journals, and articles lacking sufficient information were excluded.

Data extraction

In the first phase, titles and abstracts of journal articles were manually screened to exclude articles not connected to the topic. Articles published in language rather than English, articles that are not relevant to the topic, articles that describe the clinical activity of synthetic or semisynthetic formulation, articles published in platforms other than scientific journals, and the ones lacking sufficient information were excluded. Data was extracted from various phases, where at the beginning, titles and abstracts of journal articles were manually screened out to exclude the articles not relating to the topic. Qualified papers were studied and accessed and in any case of discrepancy, the view of the other authors was considered. In the next phase, full-text articles were reviewed and separated. No analytical tool was used for quality assessment.

Data analysis and reporting

Data obtained from literature searches were analysed and evaluated in detail. Various reported clinical studies were tabulated which included herbal tea formulation, place of study, total number of participants, study type, targeted MetSyn, dose, duration of study and outcome. Further analysis of preclinical studies included details of herbal tea like plants used to prepare herbal tea, their family, part used, formulation, targeted MetSyn and mechanism of action was also tabulated.

Results

The clinical studies involved in this systematic review were tabulated and collected following the PRISMA guidelines which included both inclusion and exclusion criteria (Fig. 2).

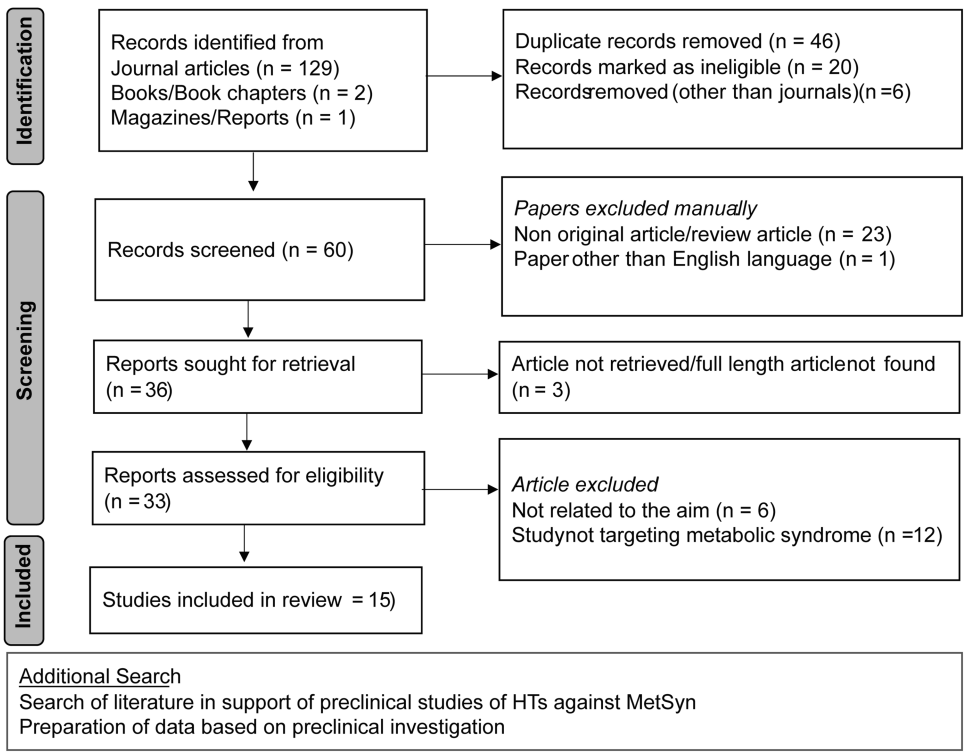

Fig. 2 Data search and screening strategy

Table 1 Clinical study data of herbal tea against metabolic syndrome

Sl no	Herbal tea formulation (combination drugs)	Place of study	Target	No. of participants		Dose	Duration	Type of study	Outcome	Reference
				Control	Intervention					
1	*Camellia sinensis*, Capsaicin, *Zingiber officinale* extracts	Iran	Weight loss and metabolic profiles	25	25	4 times/day	8 weeks	Randomized double blind placebo controlled	Supplement resulted in significant decrease in weight and body mass index. It also reduced serum insulin concentrations, homeostatic model of assessment for insulin resistance, and increased quantitative insulin sensitivity check index and plasma glutathione (GSH)	[9]
2	Yerba mate and green tea	Brazil	Paraoxonase and leptin levels	69	142	1000 mL/day	8 weeks	Randomized controlled clinical trial	Yerba mate intake had significant increase in serum levels of PON-1, while consumption of green tea did not have any significant difference in PON-1 and leptin. Increase in PON-1 levels in the yerba mate group was significantly associated with increased HDL-c	[10]
3	Matcha tea	Jordan	Overweight and obese	18	16	1 time/day	12 weeks	Non-randomized open label comparative study	The matcha tea group showed significant reductions in body weight, body mass index, waist circumference, water content, minerals, and fat mass. Additionally, it also showed a potential increase in HDL-C, a potential decrease in blood glucose, and a potential increase in HbA1c. There was also potential decrease in insulin and leptin levels, a potential increase in the activity of superoxide dismutase, and a potential decreased activity of glutathione peroxidase. It also increased IL-10 post 12 weeks	[11]

Table 1 (continued)

Sl no	Herbal tea formulation (combination drugs)	Place of study	Target	No. of participants		Dose	Duration	Type of study	Outcome	Reference
				Control	Intervention					
4	Green tea and α-glucosyl hesperidin	Japan	Obesity	27	29	146 mg/day and 178 mg/day	12 weeks	Randomized placebo controlled clinical trial	Consumption of green tea combined with α-glucosyl hesperidin significantly reduced body weight and body mass index. Additionally, it also reduced blood LDL/HDL ratio. The study concluded that, green tea combined with α-glucosyl hesperidin reduces weight gain and is more pronounced in people aged more than 50	[12]
5	Hepatomalis herbal tea, (Orlistat)	Iran	NAFLD	23	24	10 mg twice per day	12 weeks	Randomized controlled clinical trial	A significant decrease was observed in the serum level of AST, ALT, body mass index, and grade of fatty when compared with baseline	[13]
6	*Camellia sinensis*	Iran	Obesity	43	41	2 time/day	12 weeks	Randomized controlled trial	Green tea consumption significantly reduced body weight, body mass index, waist circumference and hip circumference	[14]
7	*Gynostemma pentaphyllum*	Vietnam	T2DM	12	12	6 g/daily	12 weeks	Randomized controlled double-blind trial	Consumption of *G. pentaphyllum* tea significantly reduced fasting glucose levels. HbA1c levels were also reduced by 2% units. No hypoglycaemia or any adverse events were reported	[15]
8	*Salacia reticulata* Wight., *Pterocarpus marsupium* Roxb., *Cinnamomum zeylonicum* Blume, *Artocarpus heterophyllus* Lam., *Tinospora cordifolia* (Willd.) Hook F&Thoms	Sri Lanka	T2DM	23	28	-	24 weeks	Randomized double blind cross over clinical trial	On treatment of the herbal tea, there was significant reduction of HbA1c levels comparing to the placebo group (6.29 ± 1.02 versus 6.65 ± 1.04)	[16]

Table 1 (continued)

Sl no	Herbal tea formulation (combination drugs)	Place of study	Target	No. of participants		Dose	Duration	Type of study	Outcome	Reference
				Control	Intervention					
9	*Rauvolfia-Citrus*	Denmark	T2DM	11	12	250 mL three times/day	16 weeks	Randomized double blind controlled study	RC tea-treated group showed an 11% decrease in 2-h postprandial plasma glucose relative to the 3% increase in the placebo group. It also improved blood glucose clearance with RC tea treatment was reflected in a 6% reduction in HbA1c. Phosphorylated acetyl CoA carboxylase enzyme in skeletal muscle was also significantly reduced	[17]
10	*Ilex paraguariensis*	Brazil	T2DM, prediabetes	-	58	330 mL three times/day	8 weeks	Randomized pilot study	In T2DM participants, herbal tea significantly reduced the levels of fasting glucose (25.0 mg/dL), glycated haemoglobin A1c (HbA1c) (0.85%), and low-density lipoprotein cholesterol (LDL-c) (13.5 mg/dL).In prediabetes participants, consumption of mate tea significantly reduced the levels of LDL-c (11 mg/dL), non-high-density lipoprotein cholesterol (HDL-c) (21.5 mg/dL), and triglycerides (53.0 mg/dL). It also significantly reduced their decreased significantly their consumption of total fat (14%), cholesterol (28%), and saturated (23.8%) and monounsaturated (28.0%) fatty acids, and increased their fibre intake by 35%	[18]
11	*Matricaria chamomilla* L	Iran	Glycaemic control, serum lipid profiles	32	32	3 g/150 mL hot water three times/day	8 weeks	Randomized single blind control study	Chamomille tea significantly decreased concentration of HbA1C, serum insulin levels, homeostatic model assessment for insulin resistance, total cholesterol, triglyceride, and low-density lipoprotein cholesterol	[19]

Table 1 (continued)

Sl no	Herbal tea formulation (combination drugs)	Place of study	Target	No. of participants		Dose	Duration	Type of study	Outcome	Reference
				Control	Intervention					
12	*Hibiscus sabdariffa* L	Iran	Hypertension	31	23	-	15 days	Randomized control study	On consumption of the herbal tea, there was 11.2% lowering of the systolic blood pressure and a 10.7% decrease of diastolic pressure. The pressure increased on cessation of taking herbal tea	[20]
13	*Melissa officinalis*	Iran	Hyperlipidaemia	30	28	1 g three times a day	8 weeks	Randomized double blind placebo-controlled study	On consumption of *M. officinalis* tea mean LDL and AST were significantly reduced	[21]
14	*Artocarpus heterophyllus*, *Asteracanthus longifolia*	Sri Lanka	Glucose tolerance	20	20	20 mg/kg	2.5 h	Randomized control study	The herbal tea significantly improved glucose tolerance in diabetic participants	[22]
15	*Moringa oleifera Lam*	Phil-lipines	Hyperglycemia	30	13	1 tsp. of leaf in a cup of hot water	2 h	Randomized control study	Consumption of *M. oleifera* tea significantly reduced the blood sugar levels. A mean drop of 28.15 mg/dL in the blood sugar levels was observed among the hyperglycaemic patients	[23]

A total of 132 records were screened from various databases, from which 15 studies were screened out and reported the clinical studies of various HTs against MetSyn (Table 1). The studies enrolled a total of 897 participants, and the number of participants in individual trials ranged from 23 to 211 with a mean of 59.8 ± 44.58. It was revealed that the duration of studies ranged from 2 h to 24 weeks where 10 of the reported studies were single herb HT, while the remaining 5 were poly herb HT. The trials were carried out in many nations worldwide, including 6 investigations in Iran, 2 in both Brazil and Sri Lanka, and 1 study each in Jordan, Japan, Vietnam, the Philippines and Denmark, and were conducted between the years 1990 and 2023 (Fig. 3). Detailed analysis revealed that 14 of the studies were randomized, while 1 study was non-randomized. It was also observed that all the studies dosing was different with some reporting 3 times a day, whereas all the studies reported promising efficacy, and no adverse effects were reported. Most of the HTs used in the study targeted weight loss, paraoxonase, leptin levels, NAFLD, T2DM, serum lipid profiles, hypertension and glucose tolerance. Various plants such as *Camellia sinensis*, *Matricaria chamomilla* L., *Rauvolfia-Citrus*, *Salacia reticulata* Wight., *Pterocarpus marsupium* Roxb., *Ilex paraguariensis* and *Zingiber officinale* had a substantial impact on weight and BMI reduction, as well as lowering blood insulin levels, leptin and HOMA-IR. It also markedly increased the blood levels of PON-1, Hb1A1c and HDL-c. Elevated levels of PON-1 activity potentially protect against the onset of metabolic syndrome. *Nigella sativa* and *Melissa officinalis* decreased serum levels of AST, ALT, body mass index, waist circumference and hip circumference while *Hibiscus*

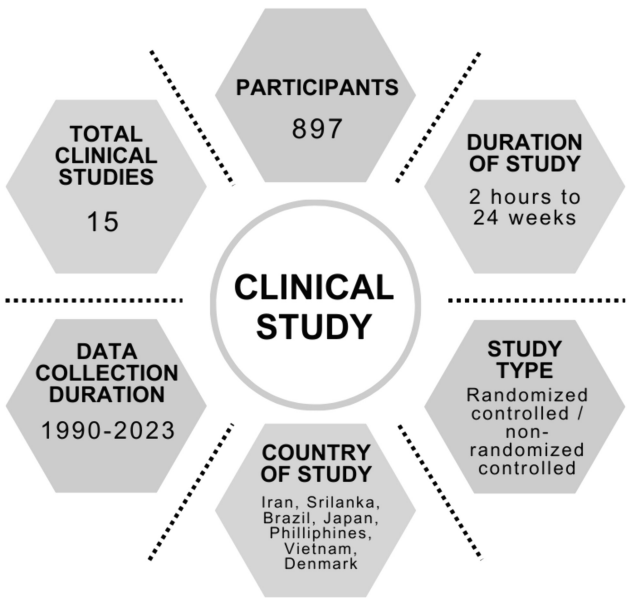

Fig. 3 Overview of selected clinical studies

Table 2 Preclinical study of various herbal teas against MetSyn

Sl no	Country	Plant name	Part used	Formulation	Targeted MetSyn	Reference
Asia						
1	China	*Camellia sinensis* (L.) Kuntze	Leaf	Infusion	Obesity, NAFLD	[24]
2	China	*Olea europaea* L	Leaf	Infusion	Lipid inhibitor, glycaemic control	[25]
3	China	*Arctium lappa*; *Ulmus rubra*; *Rumex acetosella*; *Rheum palmatum*; *Cnicus Benedictus*; *Trifolium pratense*; *Nasturtium officinale*; and *Laminaria digitata*	Root, bark	Infusion	Type 2 diabetes mellitus	[26]
4	Japan	*Matricaria chamomilla* L	Flower	Decoction	Type 2 diabetes mellitus	[27]
5	Japan	*Thea sinensis* (L.) Kuntze	Leaf	Decoction	Obesity	[28]
6	Japan	*Perilla frutescens* L	Leaf	Decoction	Diabetes mellitus	[29]
7	Japan	*Acacia molgraysima* Willd	Bark	Infusion	Obesity, diabetes	[30]
8	Korea	*Nelumbo nucifera* Gaertn	Leaf	Decoction	Obesity	[31]
9	Malayasia	*Chassalia curviflora*	Flower; leaf	Decoction	Hypertension	[32]
10	Pakistan	*Hibiscus rosa-sinensis* L.; *Zingiber officinalis* Roscoe	Flower (*H. rosa-sinensis)*; Rhizome (*Z. officinalis*)	Decoction	Obesity	[33]
11	Pakistan	*Illicium verum* Hook.f	Fruit	Decoction	Obesity	[34]
12	Phillippines	*Moringa oleifera* Lam	Leaf	Infusion	Hyperglycemia	[23]
13	Thailand	*Mentha cordifolia*	Leaf	Infusion	Hepatic glucose, lipid metabolism	[35]
14	Iran	*Eucalyptus globulus* Labill	Leaf	Decoction	Diabetes	[36]
15	Iran	*Melissa officinalis* L	Leaf	Infusion	Hyperlipidemia	[21]
Africa						
16	Nigeria	*Thymus vulgaris*, *Piper guineense*, *Murraya koenigii* and *Ocimum gratissimum*	Leaf	Infusion	Diabetes	[37]
17	Mauritania	*Gymnema sylvestre*	Leaf	Decoction	Obesity, diabetes	[38]
18	South Africa	*Athrixia phylicoides* DC	Leaf	Infusion	Glucose homeostasis, lipid parameters	[39]
19	Zambia	*Lannea edulis* Engl	Leaf	Decoction	Diabetes	[40]
20	Morocco	*Urtica dioica*	Leaf, aerial parts	Aqueous extracts	Diabetes, hypertension	[41]
21	Nigeria	*Achyranthes aspera* L	Leaf, stem and flower	Decoction	Diabetes	[42]
South America						
22	Brazil	*Ilex paraguariensis*	Leaf	Infusion	Obesity, diabetes	[43]
23	Colombia	*Ilex guayusa*	Leaf	Infusion	Diabetes	[44]
Europe						
24	Croatia	*Thymus serpyllum*	Whole plant	Infusion	Hypertension	[45]
25	England	*Medicago sativa* L	Leaf	Infusion	Diabetes	[46]
26	Spain	*Achillea millefolium*	Aerial part, leaf, flower	Infusion, decoction	Diabetes	[47]
27	Portugal	*Limonium algarvense* Erben; *Camellia sinensis* (L.) Kuntze	Flower (*L. algarvense*); leaf (*C. sinensis*)	Infusion, decoction	Diabetes	[48]
28	Poland	*Taraxacum officinale*	Leaf	Herbal Tea	Obesity, diabetes	[49]
North America						
29		*Vaccinium myrtillus*	Leaf	Decoction	Diabetes	[50]
30	USA	*Hibiscus sabdariffa* L	Flower	Infusion, decoction	Hypertension, hyperlipidaemia	[51]

Table 2 (continued)

Sl no	Country	Plant name	Part used	Formulation	Targeted MetSyn	Reference
Eurasia						
31	Russia	*Comarum palustre*	Whole plant, root, flower and seed	Infusion	Diabetes	[52]

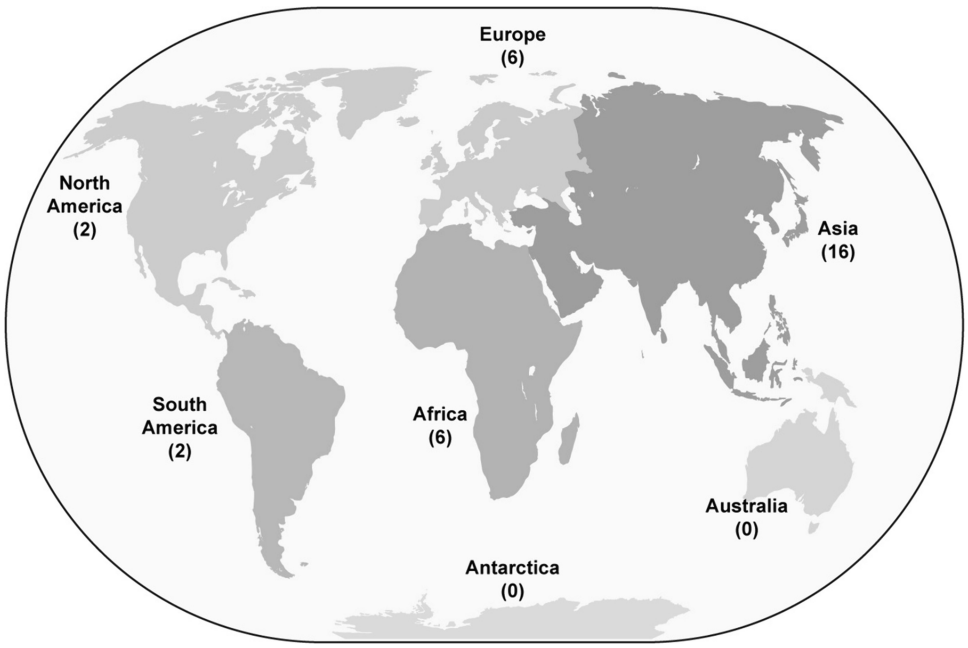

Fig. 4 Geographical representation of selected pre-clinical studies

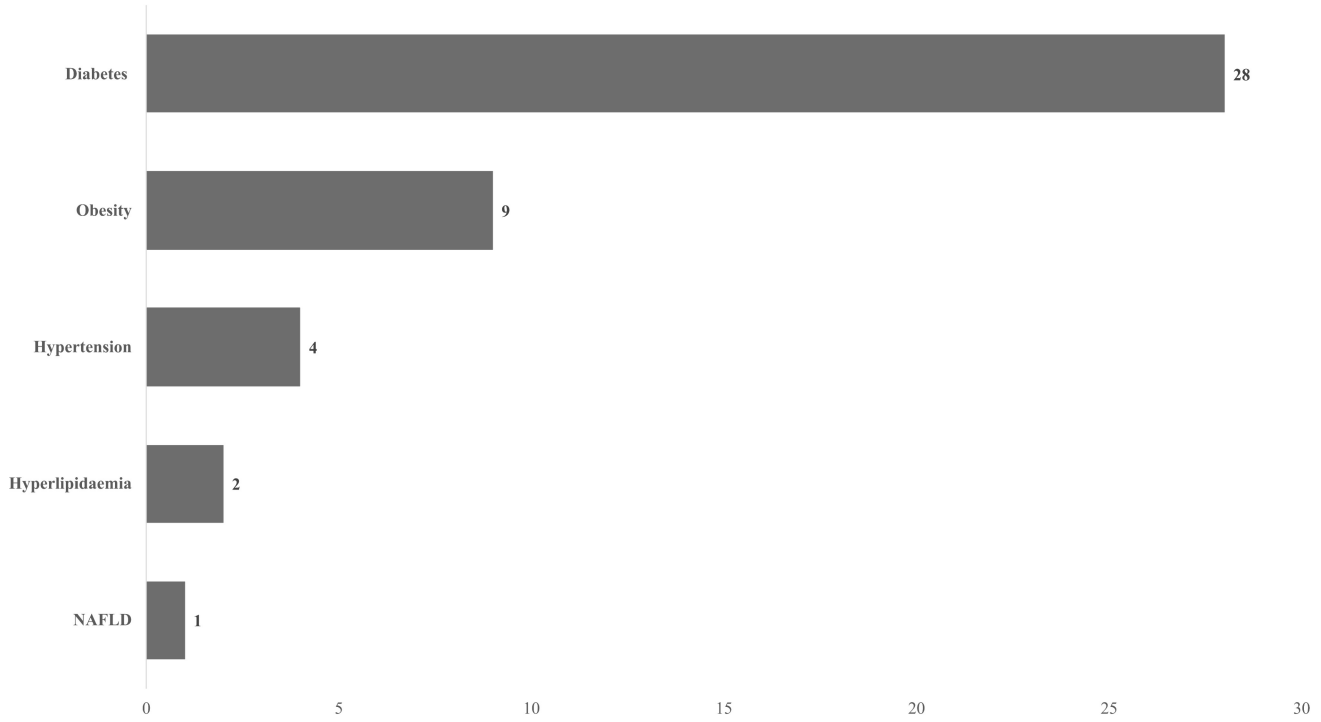

Fig. 5 Utilization of herbal tea against different metabolic syndromes

sabdariffa L. herbal tea significantly reduced 11.2% systolic blood pressure and 10.7% of diastolic pressure.

Further detailed search for preclinical studies of HT against MetSyn was conducted. The search led to the identification of 31 research which have reported the preclinical studies of HTs against metabolic syndrome (Table 2). Out of the 31 studies, 15 studies were conducted in Asia, 6 in Africa, 5 in Europe, 2 in South America, 2 in North America and 1 in Eurasia (Fig. 4). In these studies, the targeted MetSyn were diabetes (28), obesity (9), hypertension (4), hyperlipidaemia (2) and NAFLD (1) (Fig. 5). All the herbal teas were prepared in the form of infusion and decoctions. Different parts of plants were used in the formulation of HTs where the leaf was the most widely used (23); followed by flower (8); root (4), bark, seed and fruit (3); whole plant, aerial part, and rhizome (2); stem (1) (Fig. 6). Additionally, the outcome from Table 3 reveals different HTs and their various reported mechanisms of action against MetSyn. Plants like *Camellia sinensis* and *Nelumbo nucifera* reduced excessive accumulation of visceral and hepatic lipids, elevated blood glucose, dyslipidaemia, abnormal liver function and steatosis hepatitis. Treatment with *Acacia mollissima* increased the expression levels of peroxisome proliferator-activated receptor α (PPARα), PPARδ, carnitine palmitoyltransferase (CPT1), 1-aminocyclopropane-1-carboxylic acid oxidase (ACO), uncoupling protein 3 (UCP3), adiponectin and decreased expression of tumour necrosis factor (TNF-α), interleukin (IL-6), sterol regulatory element binding protein-1c (SREBP-1c), acetyl-CoA carboxylase (ACC) and fatty acid synthase (FAS) in the liver. *Chassalia curviflora* administration showed promising angiotensin-converting enzyme (ACE) inhibitory activity with an IC50 of 3.71 µg/mL against hypertension. Other plants like *Hibiscus rosa-sinensis*, *Zingiber officinale*, and *Lannea edulis* decreased kidney and liver weights and atherogenic index while decreasing the levels of aspartate transaminase (AST) and alanine transaminase (ALT). It also decreased the levels of serum total cholesterol (TC), triglycerides (TG), low-density lipoprotein (LDL) and very low-density lipoprotein (VLDL) while preventing the alterations in malondialdehyde (MDA), SOD and GSH levels. *Mentha cordifolia* and *Athrixia phylicoides* treatments led to higher carnitine palmitoyltransferase-1a (CPT-1a) gene expression and AMP-activated protein kinase (AMPK) phosphorylation, reduced fasting blood glucose (FBG) and Homeostatic Model Assessment for Insulin Resistance (HOMA-IR), and increased glucose transporter type 4 GLUT 4 activity was also associated with HTs mechanism of action (Fig. 7).

Discussion

The purpose of this systematic review was to investigate the use of HTs for the treatment of MetSyn, a heterogeneous collection of metabolic illnesses that are linked to numerous health hazards. The study examined clinical and preclinical research completed worldwide, providing an understanding of the possible advantages and mechanisms of action of several HTs in combating MetSyn. The clinical research examined in this review has shown promising findings, indicating HTs have proven effective in treating several aspects of MetSyn. These aspects include weight management, blood glucose control, lipid profiles, hypertension and glucose tolerance. The performed research included a wide range of herbal

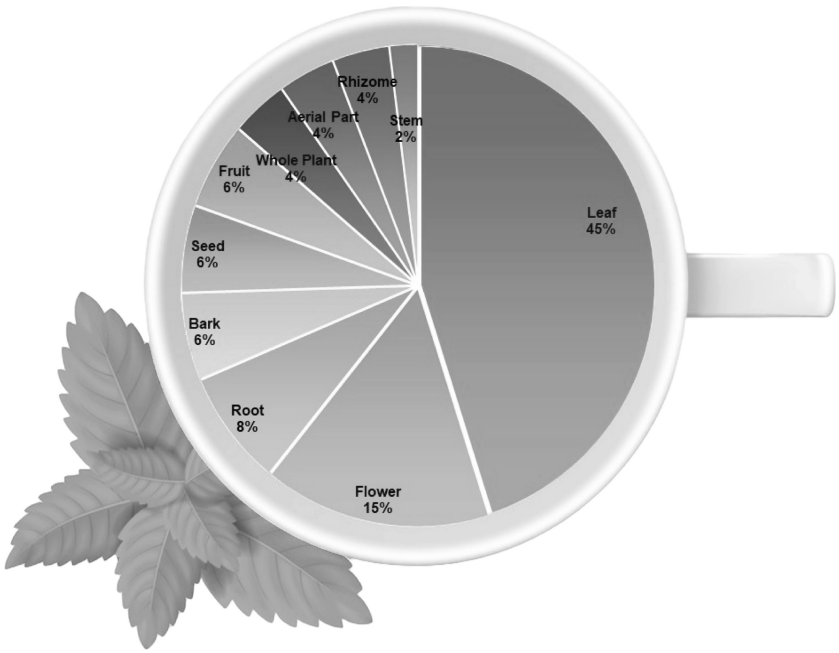

Fig. 6 Utilization of different plant parts for preparing herbal tea

Table 3 Probable MOA of various herbal teas against MetSyn

Sl no	Plant name	Family	Parts used	Tea type	Experiment type	Reported MOA/activity	Reference
1	*Camellia sinensis* (L.) Kuntze	Theaceae	Leaf	Infusion	Preclinical	Reduced excessive accumulation of visceral and hepatic lipid, elevated blood glucose, dyslipidaemia, abnormal liver function and steatosis hepatitis	[24]
2	*Olea europaea* L	Oleaceae	Leaf	Infusion	Preclinical	Enhanced anti-oxidant enzymes (SOD and GSH-Px) Prevent hepatic inflammation	[25]
3	*Matricaria chamomilla* L	Asteraceae	Flower	Decoction	Preclinical and clinical	Inhibited liver glycogen degradation Reduced blood glucose Inhibited aldose reductase (ALR2), with an IC50 value of 16.9 µg/mL	[27]
4	*Thea sinensis* (L.) Kuntze	Theaceae	Leaf	Decoction	Preclinical	Enhanced noradrenaline-induced lipolysis Accelerated the hormone-induced lipolysis Inhibited pancreatic lipase activity	[28]
5	*Acacia mollissima* Willd	Fabaceae	Bark	Infusion	Preclinical	Decreased body weight, plasma glucose and insulin Higher mRNA expression of PPARα, PPARδ, CPT1, ACO and UCP3 Lowered the expression of SREBP-1c, ACC and FAS in the liver Increased mRNA expression of adiponectin and decreased expression of TNF-α	[30]
6	*Nelumbo nucifera* Gaertn	Nelumbonaceae	Leaf	Decoction	Preclinical	Reduced total cholesterol, triglyceride and low-density lipoprotein cholesterol Better blood lipid profiles compared to control	[31]
7	*Chassalia curviflora* Thwaites	Rubiaceae	Leaf, flower	Decoction	In vitro	Promising ACE inhibitory activity with an IC50 of 3.71 µg/mL	[32]
8	*Hibiscus rosa-sinensis* L.; *Zingiber officinale* Roscoe	Malvaceae; Zingiberaceae	Flower, rhizome	Decoction	Preclinical	Decrease kidney and liver weights and atherogenic index Decreased the levels of AST, ALT, AP and SC Decreased the levels of serum TC, TG, LDL and VLDL Prevented the alterations in MDA, SOD and GSH levels	[33]
9	*Illicium verum* Hook.f	Schisandraceae	Fruit	Decoctions	Preclinical	Reduced the body weight and BMI Reduced the levels of serum total cholesterol, triglyceride, LDL and VLDL Reduced the alterations in MDA, SOD and GSH levels	[34]

Table 3 (continued)

Sl no	Plant name	Family	Parts used	Tea type	Experiment type	Reported MOA/activity	Reference
10	*Mentha cordifolia*	Lamiaceae	Leaf	Infusion	Preclinical	Decreased the level of hyperglycaemia, hyperinsulinaemia, hyperleptinaemia, and hyperlipidaemia, and increased amounts of serum adiponectin Inhibition of serum IL-6 and TNF-α Decreased the lipid accumulation and liver triglyceride content Higher carnitine palmitoyltransferase-1a (CPT-1a) gene expression and AMPK phosphorylation	[35]
11	*Athrixia phylicoides* DC	Asteraceae	Leaf	Infusion	Preclinical	Reduced weight gain by reducing visceral fat, total blood cholesterol and circulating free fatty acids Improved adipokine regulation Reduced FBG and HOMA-IR and increased GLUT 4	[39]
12	*Lannea edulis* Engl	Anacardiaceae	Leaf	Decoction	Preclinical	Decreased the levels of serum total cholesterol, triglycerides, LDL and VLDL Increased the levels of HDL	[40]
13	*Achyranthes aspera* L	Amaranthaceae	Leaf, stem and flower	Decoction	Preclinical	Reduced fasting blood glucose Significant reduction in mean serum triglyceride in herbal tea treated groups	[42]
14	*Eucalyptus globulus* Labill	Myrtaceae	Leaf	Decoction	Preclinical	Improved the hyperglycaemia, polydipsia and polyphagia	[36]
15	*Medicago sativa* L	Fabaceae	Leaf	Infusion	Preclinical	Stimulated 2-deoxy-glucose transport, glucose oxidation and incorporation of glucose into glycogen in mouse abdominal muscle Significant increase in glucose uptake and glycogenesis	[46]
16	*Limonium algarvense* Erben; *Camellia sinensis* (L.) Kuntze	Plumbaginaceae; Theaceae	Leaf; flower	Infusion, decoction	In vitro	Potent antioxidant and α-glucosidase inhibitory activity	[48]

tea formulations, including both single herb and polyherbal compositions and was carried out in many countries. Significantly, there were no recorded instances of adverse effects in any of the studies, indicating the safety of HTs as a viable treatment choice. The observed processes included enhancements in the activity of antioxidant enzymes [25, 33, 34], decreases in the buildup of lipids in the visceral and hepatic regions [24, 39], alterations in gene expression associated with lipid metabolism and inflammation [30, 35, 46] and the suppression of ACE (angiotensin-converting enzyme) activity to manage hypertension [32]. HTs have been seen to have favourable impacts on kidney and liver functionality, lipid profiles, as well as glucose metabolism [33, 35]. Nevertheless, it is important to acknowledge that most of the clinical trials discussed did not provide registration numbers, a fundamental need for ensuring openness in the field of clinical research [53]. Although the effectiveness of treating MetSyn directly is uncertain, current research is making progress in identifying several points in the disease's progression that can be targeted [54]. Recognizing the progression of metabolic syndrome is essential for effectively treating, preventing and reversing the condition. By doing a thorough analysis of the patient's medical history and physical examination, providing education to the patient and investigating the underlying variables that contribute to the metabolic syndrome, clinicians cannot only treat the condition but also potentially modify the course of disease progression [55].

Strengths and limitations

The strength of this study is that it offers important knowledge into the possible processes by which herbal teas might treat MetSyn both clinically and preclinically. These mechanisms include increased antioxidant activity, regulation of gene expression linked to lipid metabolism and inflammation and inhibition of angiotensin-converting enzyme activity. Although the study has discovered encouraging results, it acknowledges the necessity for more in-depth research to confirm the long-term safety and effectiveness of herbal teas for managing MetSyn. This demonstrates a dedication to using scientific data and constantly improving healthcare treatments. The strength of the research lies in its detailed approach, thorough analysis, and unique perspectives on the potential of herbal teas in treating the global issue of MetSyn. Additionally, it is noteworthy to emphasize that our study is the first effort to conduct a systematic review of HT on a global scale, specifically focusing on its impact on MetSyn.

Besides various strengths, the study also had a few limitations. Very few studies were only conducted on herbal tea clinically across a few countries based on which the possible benefits and assurity of using herbal tea cannot be ruled out. Further studies on a higher number of patients on a larger scale can only confirm these. Additionally, a significant majority of the clinical trials included in the analysis did not provide registration numbers, which are crucial for

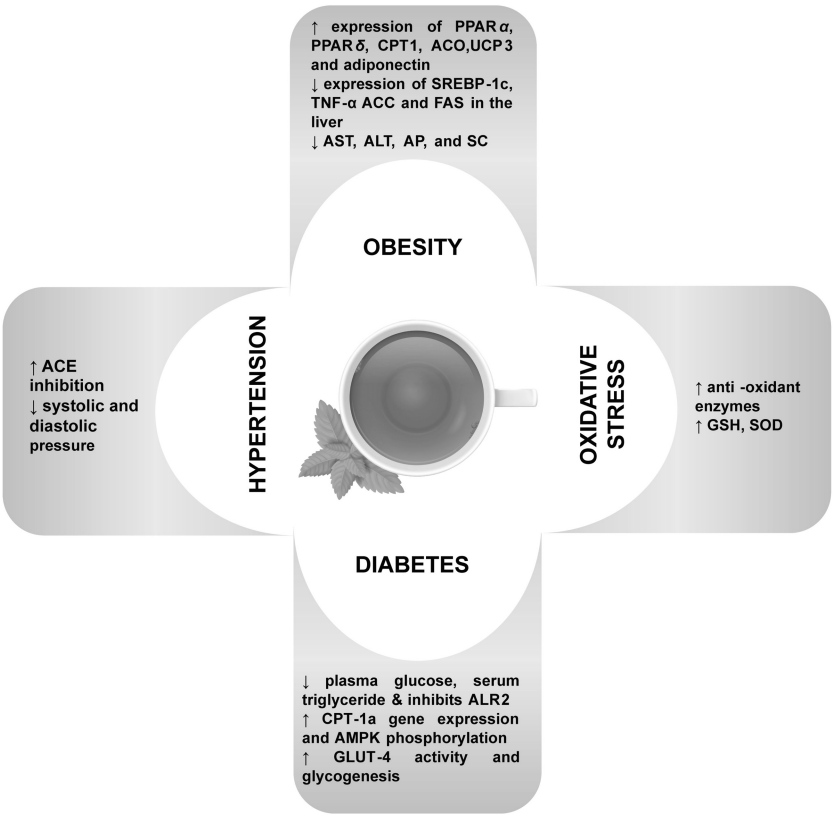

Fig. 7 Reported MOA of herbal tea against various metabolic syndromes

guaranteeing transparency and credibility in clinical research [53]. The absence of this information restricts the capacity to authenticate the credibility of the research and gives rise to concerns regarding possible bias or selective reporting. Moreover, the study incorporated several clinical studies, most of which had brief study durations, spanning from 2 h to 24 weeks. The short duration of this follow-up period may not accurately assess the long-term impact and safety of herbal teas in treating MetSyn.

Conclusion

Herbal teas provide a potentially helpful approach to tackle the rising prevalence of MetSyn on a worldwide scale. Further research and assessment of these natural medicines are warranted due to their few side effects and various bioactive components, making them potential supplementary or alternative treatments for a broad spectrum of MetSyn. Also, it is essential to conduct extensive clinical studies that conform to valid registration protocols and include long-term follow-up to definitively prove the effectiveness and safety of these interventions. While the findings show potential, further investigation is required to validate the enduring safety and efficacy of HTs in the management of MetSyn.

Abbreviations NAFLD: Non-alcoholic fatty liver disease; ACE: Angiotensin-converting enzyme; PPARα: Peroxisome proliferator-activated receptor alpha; PPARγ: Peroxisome proliferator-activated receptor gamma; CPT1: Carnitine palmitoyltransferase 1; ACO: Acyl CoA oxidase; UCP3: Uncoupling protein 3; SREBP-1c: Sterol regulatory element binding protein-1c; TNF-α: Tumour necrosis factor-alpha; ACC: Acetyl-CoA carboxylase; FAS: Fatty acid synthase; AST: Aspartate transaminase; ALT: Alanine transaminase; AP: Alkaline phosphatase; SC: Serum creatinine; GSH: Glutathione; SOD: Superoxide dismutase; ALR2: Aldol reductase 2; GLUT-4: Glucose transporter type 4; AMPK: AMP-activated protein kinase

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Declarations

Conflict of interest The authors declare no competing interests.

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