



Curcuma longa and curcumin on metabolic syndrome: a systematic review

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Background: Metabolic syndrome (MS) is a complex condition that predisposes the population to an increased risk of cardiovascular diseases (CVD), meaning a high burden to health care systems. Medicinal plants and natural compounds have gained ground in the therapeutic approach to MS due to their effectiveness, reduced costs, and few adverse effects. Among many plants with positive impacts to improve MS risk factors is *Curcuma longa*. This plant can benefit the treatment of several pathological conditions since it exhibits actions such as anti-inflammatory and antioxidant. By virtue of these reasons, this study aims to perform a systematic review of the effects of *Curcuma longa* on MS.

Methods: PubMed, EMBASE, and COCHRANE databases were searched, and PRISMA guidelines were followed to build this review.

Results: The results showed that eleven clinical trials met the inclusion criteria.

Discussion: These studies showed that this plant could improve Body Mass Index, glycemia, lipids (reducing triglycerides and increasing HDL-C), adiponectin, C reactive proteins, and cytokines levels [tumor necrosis factor- α (TNF- α), transforming growth factor- β (TGF- β), and monocyte chemoattractant protein-1 (MCP-1)]. No severe adverse effects were referenced in the included studies. We conclude that the use of *Curcuma longa* can help control risk factors in patients with MS. However, more clinical trials are necessary to show the doses and formulations that should be used to prevent or as adjuvants to treat metabolic conditions associated with MS.

Keywords: *Curcuma longa*; anti-inflammatory; antioxidant; cancer

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Introduction

Metabolic syndrome (MS) is a complex condition predisposes the population to an increased risk of cardiovascular diseases (CVD). It is characterized by at least three risk factors: elevated blood pressure, triglycerides, glycemia, waist

circumference, and reduced levels of HDL-C. These clusters of factors increase inflammatory and oxidative processes that promote and aggravate other metabolic conditions that increase morbidity and mortality (1,2).

Subjects with MS usually develop diabetes, dyslipidemia,

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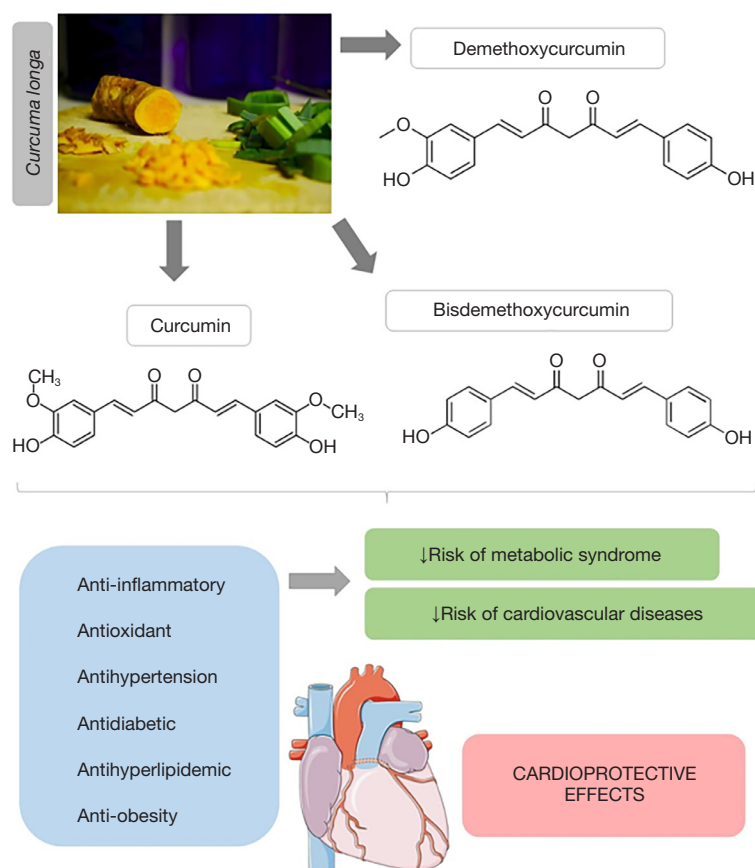


Figure 1 *Curcuma longa* main bioactive compounds and the effects on metabolic diseases. ↓, decrease.

hypertension, and abdominal obesity. This condition, which is more common in adults, is also increasing in children and adolescents. This is due to unhealthy lifestyle habits with high consumption of carbohydrates, fats, processed and ultra-processed foods, and lack of physical exercise. Thus, lifestyle modification strategies, drug treatment, and adjuvant therapies are essential to improve risk factors. Medicinal plants and natural compounds have gained ground in the therapeutic approach to MS due to their effectiveness, reduced costs, and few adverse effects. Among many plants with positive impacts to improve MS risk factors is *Curcuma longa* (3-5).

Curcuma longa, popularly known as or turmeric, belongs to the family Zingiberaceae, which grows in Indian and tropical countries and has been used in Indian Ayurvedic medicine for more than 6,000 years. Due to its golden color and slightly bitter taste, turmeric is considered a versatile spice and is very used in culinary preparations (6-8).

Turmeric shows diversity in its chemical composition, and the quality and amount of the bioactive compounds can vary according to locations and growing conditions. Many phenolic compounds and terpenoids are present in this plant. The main compounds of the rhizomes are curcuminoids: curcumin (77%) that is responsible for the yellow color bisdemethoxycurcumin (17%), and demethoxycurcumin (3%) (9,10). Curcumin is broadly used as a color-inducing agent and was designated as a food additive, and is *Generally Recognized as Safe* by the American Food and Drug Administration (11).

Several studies have shown that *Curcuma longa* can benefit the treatment of several pathological conditions since it exhibits anti-inflammatory, antioxidant, antimicrobial, antibacterial, antiviral, antifungal anti-hypoglycemic, antiobesity, anti-hypertension, neuroprotective, antidepressant, and chemo-preventive (12-14). *Figure 1* shows the main compounds and some effects of *Curcuma longa*.

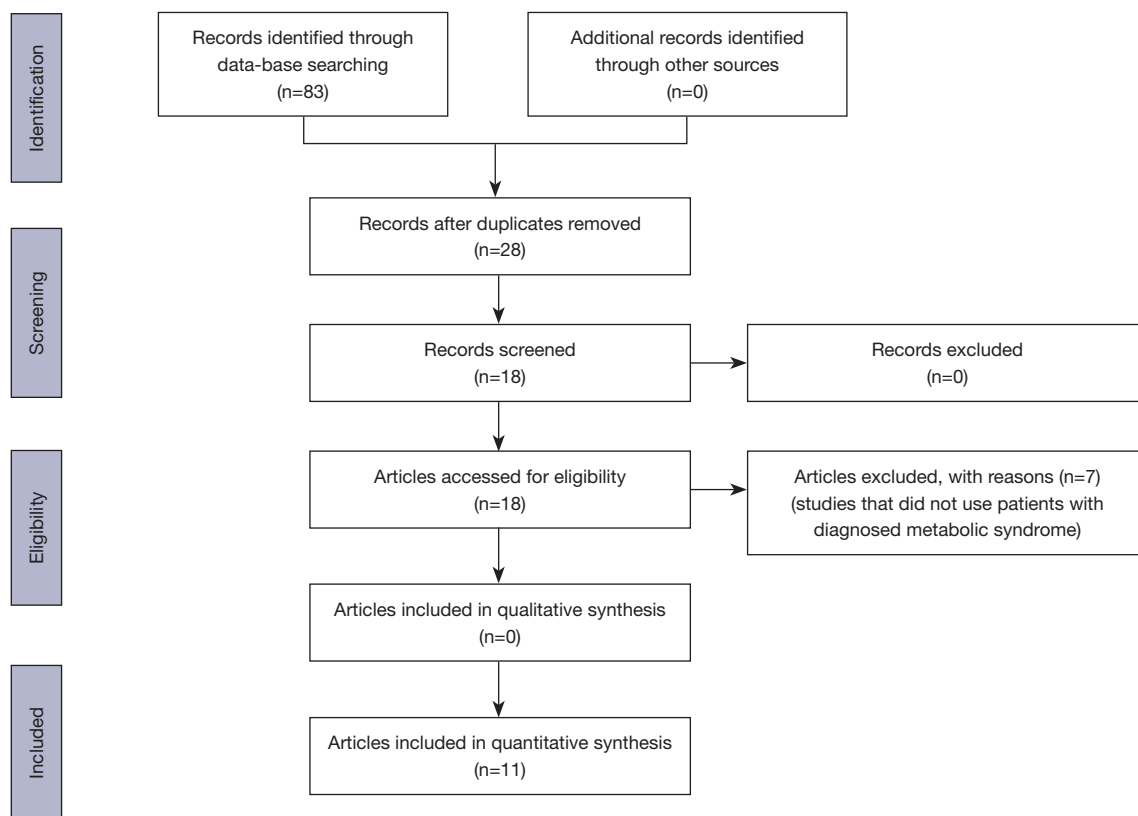


Figure 2 Flow diagram showing the study selection.

Due to the properties mentioned earlier of *Curcuma longa*, this study aims to perform a systematic review of the effects of this plant on MS.

We present the following article in accordance with the PRISMA reporting checklist (available at <https://dx.doi.org/10.21037/lcm-21-25>).

Methods

Focal question

The focal question for this systematic review was: Can *Curcuma longa* show benefits on MS?

Language

Only studies published in English were selected.

Databases

This review was built with studies published in PubMed,

EMBASE, and COCHRANE databases. The mesh-terms were *Curcuma longa* or curcuminoids or curcumin and MS. PRISMA (Preferred Reporting Items for a Systematic Review and Meta-Analysis) guidelines were used to perform this review (15) (Figure 2).

Study selection

This review was built with studies that associated *Curcuma longa* or *Curcuminoids* or curcumin [Code of Federal Regulations (FDA): §73.600] and MS. The inclusion criteria enclosed Randomized clinical trials (RCTs), double-blind RCTs, and placebo-controlled studies. We only used full-text studies that were performed with MS patients and not those with the plant and isolated MS risk factors. We also considered PICO (population, intervention, comparison and outcomes) format.

The exclusion criteria were studies not in English, reviews, studies with animals or *in vitro*, clinical trials that associated different plant formulations, case reports, poster presentations, and editorials. Reviews were examined to build the discussion but were not included in the systematic review.

Data extraction

The period for the search included clinical trials performed in the past ten years (February 2011 to June 2021). Two judges performed data extraction. A third judge resolved disagreements between them.

The selected studies are included in *Table 1*.

Quality assessment

The quality of the included studies followed the Cochrane Handbook for Systematic Reviews of Interventions was used to perform this quality assessment.

Results

Table 1 shows the results of this systematic review. After using the inclusion and exclusion criteria, eleven randomized trials that investigated the effects of *Curcuma longa* in patients with MS were included. Both sexes were present in all the studies. Most of them were double-blinded studies. Of these studies, five (22-26) have used the same group of patients from Iran, and the other four, also in Iran (17,18,20,21), present this same characteristic. The other studies were performed in Taiwan (16) and Italy (19).

The studies presented in *Table 1* show that *Curcuma longa* can bring benefits in patients with MS. These studies showed that this plant can improve Body Mass Index, weight gain, glycemia, lipids (reduction of triglycerides and increase of HDL-C), adiponectin, C reactive proteins, and cytokines levels [tumor necrosis factor- α (TNF- α), transforming growth factor- β (TGF- β), and monocyte chemoattractant protein-1 (MCP-1)]. No severe adverse effects were reported in the included studies. In *Table 2* we show the risk of bias for the included studies.

Discussion

MS

MS has a multifactorial etiology and is considered one of the major public health problems in people worldwide. It is observed that rates of 30% can afflict some populations and the consequences are a high burden to health systems. There are different diagnostic criteria for MS, but most enclose risk factors for developing CVD. These risks are altered levels (high levels) of blood glucose and triglycerides, obesity, hypertension, and reduced HDL-C (27-29).

The National Cholesterol Education Program ATP III

(NCEP ATP III) criteria comprise the presence of any three of the following conditions: fasting glucose ≥ 110 mg/dL; triglycerides levels ≥ 150 mg/dL; HDL-C levels ≤ 40 mg (men) or ≤ 50 mg/dL (women); waist circumference (WC) ≥ 102 cm (men) or ≥ 88 cm (women); and blood pressure $\geq 130/85$ mmHg. The criteria established for the International Diabetes Federation (IDF, 2006) considers fasting glucose ≥ 100 mg/dL, triglycerides levels ≥ 150 mg/dL; HDL-C levels ≤ 40 mg (men) or ≤ 50 mg/dL (women); WC > 90 cm for men and > 80 cm for women; and blood pressure $\geq 130/85$ mmHg. Following IDF (2006), the patient has MS when possessing altered WC with the presence of two other risk factors (IDF, 2006) (2,30-33).

The multisystemic character of MS denotes that many chronic-degenerative diseases that are also associated with oxidative stress, a pro-inflammatory state, and atherosclerosis are superimposed in "dysmetabolic" subjects. The most common associated conditions are CVD, non-alcoholic steatohepatitis, chronic kidney disease, neurodegeneration, and cancer (34-38).

Understanding the components of MS and its metabolic and systemic repercussions is essential to take measures to contain the progression of the number of affected patients. Lifestyle changes are imperative; however, the search for therapeutic strategies that control risk factors is important to reduce the long-term complications of MS. Medicinal plants and their bioactive compounds can collaborate to prevent or treat risk factors at attractive prices and low side effects.

Curcuma longa, curcumin, and MS

Curcuma longa and its derivatives, such as curcumin, have been used for medical purposes to treat several conditions since ancient times. Many of the effects of this plant are related to its antioxidant and anti-inflammatory properties. Several diseases are related to inflammation and oxidative damage. Oxidation leads to chronic inflammation, and chronic inflammation increases oxidative stress. Alone or together, these conditions mediate most known chronic diseases. Hyperglycemia, for example, can lead to the increased entrance of glucose in non-insulin-dependent tissues and cause the production of advanced glycation products (AGEs), which are reactive species related to numerous events that trigger metabolic changes. Obesity is considered a low-grade inflammatory process that leads to a shift in the secretory pattern of macrophages from M2 (related to the release of anti-inflammatory mediators)

Table 1 Descriptive table of the included studies

Reference	Local	Patients	Intervention and time of intervention	Outcomes	Adverse effects
Yang <i>et al.</i> (16)	Taiwan	Randomized, double-blind, placebo-controlled trial with 65 ♂ and ♀ subjects (59.30±12.00 y) with MS who have had stable medical treatment for at least 6 m prior to the study enrollment	Subjects were randomized into 2 groups: curcumin (n=33, 12 , 59.03±10.10 y, 630 mg curcumin extract capsule 3× d) and placebo (n=32, 17 , 59.61±14.09, placebo capsule 3× d)/12 w	Subjects that received curcumin presented anti-lipid effects but the intake was not associated with weight or glucose homeostasis	Two participants in the curcumin group had mild diarrhea and nausea as adverse effects
Panahi <i>et al.</i> (17)	Iran	Randomized, double-blind, placebo-controlled, parallel-group design trial with 117 ♂ and ♀ subjects (25–75 y) with MS	Subjects were randomized into 2 groups: curcumin (n=59, 44.80±8.67 y, 23 , 1,000 mg/d +10 mg of piperine to improve the bioavailability of the curcumin) and placebo (n=58, 43.46±9.70 y, 27 , 1,000 mg of placebo +10 mg of piperine)/8 w	Curcumin significantly reduced serum LDL-C, non-HDL-C, total cholesterol, triglycerides, and Lp(a). Curcumin elevated HDL-C	Diarrhea (n=2), constipation (n=2), headache (n=1), and skin rash (n=2) in the curcumin group. Headache (n=2) and constipation (n=1) in the placebo group
Pahani <i>et al.</i> (18)	Iran	Phase III, randomized, double-blind, placebo-controlled study with a parallel-group design. This study had 117 and subjects with MS and that were not receiving lipid-lowering therapy	Subjects were randomized into 2 groups: curcumin (n=59, 44.80±8.67 y, 23 , 1,000 mg/day +10 mg of piperine to improve the bioavailability of the curcumin) and placebo (n=58, 43.46±9.70 y, 27 , placebo)/8 w	Curcumin-piperine combination significantly improved serum superoxide dismutase activities and reduced malondialdehyde concentrations. The treated group showed reduced circulating CRP and significantly improved oxidative and inflammatory ambiances	NR
Di Pierro <i>et al.</i> (19)	Italy	Randomized, controlled clinical trial with 17 and 27 caucasian overweight subjects (18–70 y) with MS and BMI between 25.0–29.9 under 30 d with diet or with another intervention of lifestyle and have shown less than 2% of weight loss	Subjects were randomized into group 1: 800 mg/dose/d of <i>Curcuma longa</i> extract with 95% of curcumin + lifestyle intervention, and G2: phosphatidylserine + lifestyle intervention (400 mg/dose/d of pure phosphatidylserine)/1 m	Participants of group 1 presented a reduction in the weight and fat percentage, improved hip circumference reduction, and enhanced BMI reduction (these effects were no significant in G2)	Gastric burning in phosphatidylserine group
Pahani <i>et al.</i> (20)	Iran	Randomized, double-blind, placebo-controlled trial with parallel group design with 117 and with MS and that were not receiving lipid-lowering therapy	Subjects were randomized into 2 groups: curcumin (n=59, 44.80±8.67 y, 23 , 1,000 mg/d +10 mg of piperine/day to improve the bioavailability of the curcumin) and placebo (n=58, 43.46±9.70 y, 27 , placebo +10 mg/d of piperine)/8 w	Curcumin was associated with a significant elevation in serum adiponectin and reduction in leptin levels	Diarrhea (n=2), constipation (n=2), headache (n=1), and skin rash (n=2) were reported in the curcumin group. Headache (n=2) and constipation (n=1) in the placebo group
Pahani <i>et al.</i> (21)	Iran	Randomized, double-blind, placebo-controlled trial with 117 and subjects with MS and that were not receiving lipid-lowering therapy	Subjects were randomized into 2 groups: curcumin (n=59, 44.80±8.67 y, 23 , 1,000 mg/d +10 mg of piperine to improve the bioavailability of the curcumin) and placebo (n=58, 43.46±9.70 y, 27 , placebo +10 mg of piperine). The study intervention took 8 weeks to be completed	The curcumin supplementation was associated with a significant decrease in serum cytokines levels (TNF- , IL-6, TGF- and MCP-1) of subjects with MS	Diarrhea (n=2), constipation (n=2), headache (n=1), and skin rash (n=2) in the curcumin group. Headache (n=2) and constipation (n=1) in the placebo group
Ghazimoradi <i>et al.</i> (22)	Iran	Randomized, double-blind, placebo-controlled study with 120 and participants (18–65 y) affected with MS and that did not receive nutritional supplements and drugs in the past 3–6 m before the study	Subjects were randomized into 3 groups: phospholipidated curcumin (1,000 mg/d of phospholipidated curcumin), curcumin (1,000 mg/d), and placebo/6 w	In the final analysis of the study, the results showed that the supplementation with curcumin did not suggest any improvements of pro-oxidant-antioxidant balance in patients affected by MS	Nausea (n=1 group 1), and abdominal pain (n=1 placebo group)
Mohammadi <i>et al.</i> (23)	Iran	Randomized, placebo-controlled clinical trial with 120 and participants (18–65 y) diagnosed with MS	Participants were randomized into 3 groups: absorption-enhanced curcumin-phospholipid complex group (40.05±10.48 y, 25 , 1 g/d, equivalent to 200 mg/d of pure curcumin, n=40), unformulated curcumin group (37.52±9.47 y, 31 , 1 g/d, n=40) and placebo group (control group, 38.59±10.28 y, 30 , n=40)/6 w	Any curcumin formulations used in the study interventions suggested significant effects on serum levels of vitamin E	Group 1: hypersensitivity (n=1, sneezing and cold sore). Group 2: cold sore (n=1) and nausea (n=1)
Mohammadi <i>et al.</i> (24)	Iran	Randomized, double-blind, placebo-controlled clinical trial with 120 and subjects (18–65 y) diagnosed with MS	Participants were randomized into 3 groups: curcumin (n=40, 500 mg/2× d for 6 w, 31 , 37.52±9.47 y), phospholipidated curcumin (n=40, 500 mg/2× d/6 w, 25 , 40.05±10.48 y), and placebo (500 mg/2× d, 30 , 38.59±10.28)	Both curcumin and phospholipidated curcumin supplementations did not show effects on serum levels of anti-Hsp 27 in patients with MS	NR
Safarian <i>et al.</i> (25)	Iran	Randomized, double-blind, placebo-controlled study with 120 and participants (18–65 y) diagnosed with MS	Participants were randomized into 3 groups: phospholipidated curcumin (n=40, 25 , 40±10.4 y, 1,000 mg/d of phospholipidated curcumin/6 w), curcumin (n=40, 31 , 37.5±9.4 y, 1,000 mg/d of curcumin/6 w) and placebo (n=40, 30 , 38.5±10.2 y, 1,000 mg of placebo/d/6 w)	Serum Zn/Cu levels in phospholipidated curcumin and in curcumin groups were higher than control group, being more significant in the phospholipidated curcumin group	One subject of the phospholipidated curcumin group did not complete the study because of nausea, as well as 2 participants of the curcumin group because of cold sore and nausea and 1 participant of the placebo group because of abdominal pain
Shirmohammadi <i>et al.</i> (26)	Iran	Randomized, double-blind, placebo-controlled with 80 and subjects (18–65 y) with MS	Participants were randomized into 2 groups: treatment (curcumin-phospholipidated complex group, 40.05±10.48 y, 25 , 1,000 mg of curcumin-phosphatidylcholine complex for 6 w, n=40) and control (placebo, 38.59±10.28 y, 30/6 w)	The study intervention with curcumin-phospholipid complex did not suggest any significant effects of the curcumin complex on the serum levels of cathepsin D of the participants diagnosed with MS	In the curcumin-phospholipid group, 1 subject dropped out the study due to nausea. In the placebo group, 1 subject dropped out due to abdominal pain

y, year; m, month; d, day; w, week; MS, metabolic syndrome; NR, not reported; CRP, C reactive protein; TNF- , tumor necrosis factor- ; IL-6, interleukin-6; TGF- , transforming growth factor- ; MCP-1, monocyte chemoattractant protein-1.

Table 2 Descriptive table of the biases of the included RCTs

Reference	Question focus	Appropriate randomization	Allocation blinding	Double-blind	Losses (<20%)	Prognostics or demographic characteristics	Outcomes	Intention to treat analysis	Sample calculation	Adequate follow-up
Yang <i>et al.</i> (16)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	NR	No
Pahani <i>et al.</i> (17)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NR	Yes
Pahani <i>et al.</i> (18)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NR	Yes
Di Pierro <i>et al.</i> (19)	Yes	Yes	No	No	Yes	Yes	Yes	Yes	NR	Yes
Pahani <i>et al.</i> (20)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NR	Yes
Pahani <i>et al.</i> (21)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NR	Yes
Ghazimoradi <i>et al.</i> (22)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mohammadi <i>et al.</i> (23)	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes
Mohammadi <i>et al.</i> (24)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Safarian <i>et al.</i> (25)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shirmohammadi <i>et al.</i> (26)	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes

NR, not reported; RCTs, randomized clinical trials.

to M1 (associated with the release of pro-inflammatory mediators), resulting in a low-grade inflammatory state. Adipose tissue, especially visceral tissue, releases pro-inflammatory mediators such as interleukin 6 (IL-6), TNF- α , resistin, and reduces production of beneficial mediators such as adiponectin and IL-10. Obesity is related to hypertension, insulin resistance, and dyslipidemia, which are risk factors for establishing MS (31,39-41).

Curcumin has been shown to decrease glycemia and insulin levels and improve insulin resistance. It is also associated with reducing the levels of resistin, IL-1 β , IL-6, IL-8, and TNF- α in patients with type 2 diabetes mellitus (T2DM). In these patients, it is shown that curcumin increases adiponectin levels (42). For these reasons, these compounds can interfere with glucose homeostasis, chronic diabetic complications, and vascular risk (43). Also, in patients with T2DM, this compound improved the lipid profile and the total antioxidant capacity (44,45), supporting evidence that this compound can reduce cardiometabolic risks (39,46-49).

In an animal model, the authors investigated the effects of different commercial supplements with *Curcuma longa*.

The antioxidant activity and glucose diffusion and starch digestion were measured, and the results showed that the five different supplements were able to reduce glucose diffusion and the activity of α -glucosidase enzyme, and inhibited lipid peroxidation. However, the biological activity of the *Curcuma longa* supplements varies among them (50).

A study showed that the use of *Curcuma longa* extract in overweight or hypertension middle-aged and elderly participants significantly reduced glycemia, glycated hemoglobin, triglycerides, and increased HDL-C. The treated patients also showed significant improvement of chronic low-grade inflammation, contributing to the amelioration of metabolic disorders (51). *Figure 3* shows the effects of curcumin in the components of the MS.

A recent systematic review and meta-analysis to investigate the effects of curcuminoids on triglycerides, cholesterol, LDL, and HDL of adults with prediabetes, diabetes, overweight, dyslipidemia, MS, or nonalcoholic fatty liver disease performed by Yuan *et al.* (52) showed that curcuminoids can significantly improve lipid profile in these subjects. Moreover, Ganjali *et al.* (53) showed that curcumin

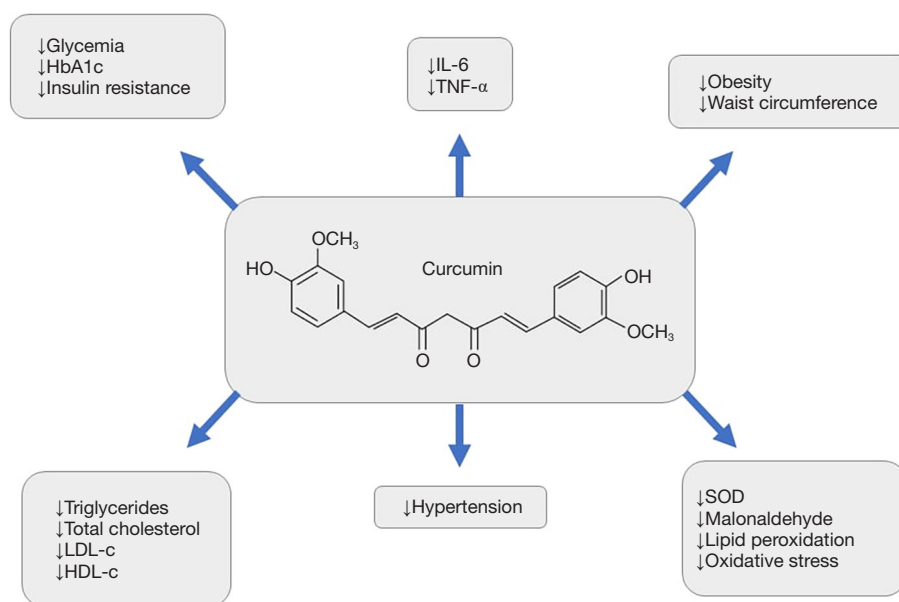


Figure 3 The effects of curcumin in inflammation, oxidative stress and risk factors of metabolic syndrome. ↑, increase; ↓, decrease. SOD, superoxide dismutase; IL-6, interleukin 6; TNF- α , tumor necrosis factor- α .

can modulate biomarkers of HDL-C function, such as the activity and the levels of apolipoprotein-AI, cholesteryl ester transfer protein, lecithin cholesterol acyl transferase, paraoxonase 1, and Myeloperoxidase. Besides that, this compound can subsequently ameliorate conditions in which HDL-C is dysfunctional and could work as a promising therapeutic drug in the future.

Choi *et al.* (54) evaluated the association among *Curcuma longa* consumers with hypertension and blood levels of heavy metals in Korean subjects. They found that participants that had intake a curry dish more than once per month during the previous year exhibited significantly reduced Pb, Hg, and Cd concentrations. The concentrations of these metals were significantly linked to the prevalence of hypertension. Indeed, the *Curcuma longa* intake decreased the risk of hypertension prevalence. In mice, when captopril was associated with *Curcuma longa*, there was a reduction of cardiac muscle and left ventricle thickness in animals with hypertension, suggesting that this association can prevent cardiac complications of hypertension (55).

Curcuma longa can reduce body weight and body fat percentage in obese and overweight females. Furthermore, it can prevent excessive weight gain and play an important role in regulating inflammatory reactions observed in the overweight subjects, helping reduce the body-weight

excess (56,57).

In addition to these studies described above, it is possible to observe that the RCTs presented in *Table 1* also show positive effects of curcumin in MS patients; however, the parameters evaluated were varied. Only two studies investigated the effects of curcumin on dyslipidemia (16,17), and both found an improvement in the lipid profile. One study showed the benefits of reducing body weight, waist circumference, and fat percentage (19). The other studies did not assess the outcomes in parameters directly related to the diagnosis of MS. One study showed improvement in superoxide dismutase activity and improved malonaldehyde levels and reduced C reactive protein (CRP) levels (18). The levels of adiponectin were increased, and leptin levels were decreased in other RCTs (20). The pro-inflammatory parameters (TNF- α and IL-6) were also improved in one RCT (21). Safarian *et al.* (25) showed improvement in the levels of Zn/Cu in patients treated with curcumin. The remaining four included RCT found no effects of curcumin on vitamin E levels (23), oxidant-antioxidant balance (22), anti-Hsp 27 (24), and cathepsin D levels (26). The improvement in body weight, glycemia, lipids, and biomarkers of inflammation reduce the risk of developing diabetes, CVD, cancer, and other conditions associated with the presence of MS (*Figures 4,5*).

However, some relevant biases can be mentioned in

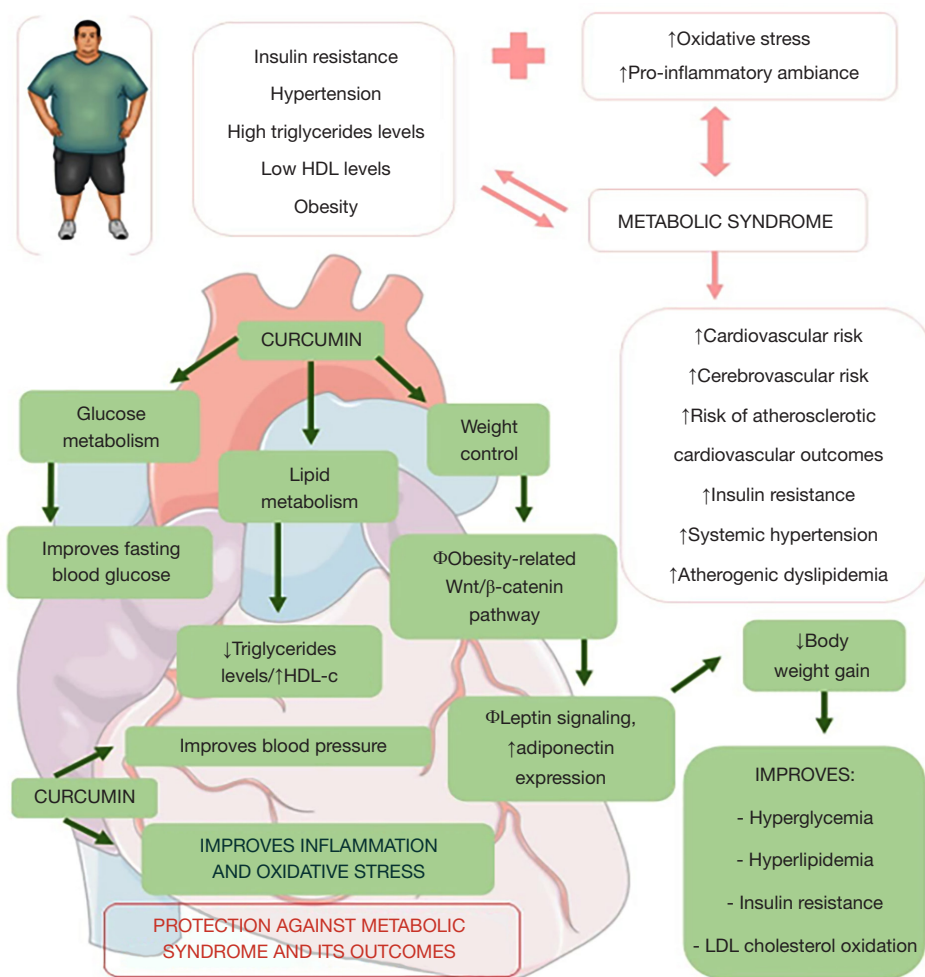


Figure 4 The risk factors of metabolic syndrome and its consequences, and the role of curcumin. ↑, increase; ↓, decrease; Φ, inhibition.

these studies, such as the high number of patients who discontinued the study, not reporting adverse events, and not-blinded studies. Furthermore, as described above, many of the eleven studies included in this review used the same patients and evaluated different variables.

Despite the limitations presented by the included studies, the results of this review may help professionals when using *Curcuma longa* in the management of patients with MS.

Conclusions

We conclude that the use of *Curcuma longa* can help control risk factors in patients with MS. However, more clinical trials are necessary to show the doses and formulations

that should be used in the prevention or as adjuvants in the treatment of metabolic conditions associated with MS.

Limitations

The limitations of this study lie in the fact that the included studies are very heterogeneous with regard to the doses administered and the formulation of *Curcuma longa*.

Summary

Curcuma longa and curcumin show impressive anti-inflammatory and antioxidant actions and can improve the risk factors that characterize the presence of MS.

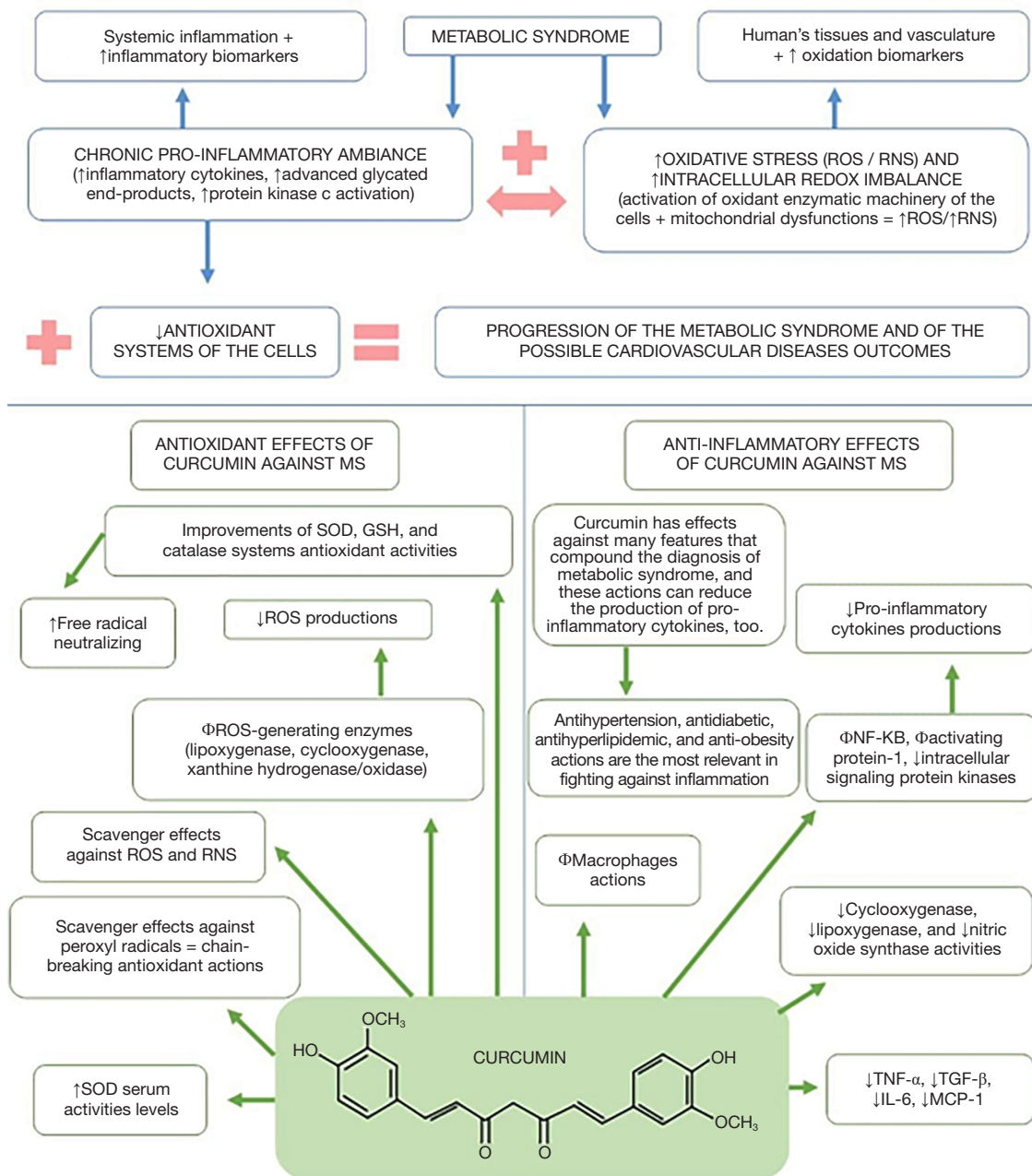


Figure 5 The role of curcumin against inflammation and oxidative stress observed in MS. ↑, increase; ↓, decrease; Φ, inhibition. ROS, reactive oxygen species; RNS, reactive nitrogen species; MS, metabolic syndrome; SOD, superoxide dismutase; GSH, reduced glutathione; NF-KB, nuclear factor kappa B; TNF-α, tumor necrosis factor-α; TGF-β, transforming growth factor beta; IL-6, interleukin 6; MCP-1, chemoattractant protein 1.

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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