



International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Operating Publisher
SciFormat Publishing Inc.
ISNI: 0000 0005 1449 8214

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ARTICLE TITLE	CURCUMIN SUPPLEMENTATION IN THE PREVENTION AND MANAGEMENT OF METABOLIC SYNDROME: CURRENT EVIDENCE AND PUBLIC HEALTH PERSPECTIVES
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DOI	https://doi.org/10.31435/ijitss.3(51).2026.6135
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RECEIVED	04 August 2026
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ACCEPTED	17 September 2026
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PUBLISHED	28 September 2026
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CURCUMIN SUPPLEMENTATION IN THE PREVENTION AND MANAGEMENT OF METABOLIC SYNDROME: CURRENT EVIDENCE AND PUBLIC HEALTH PERSPECTIVES

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ABSTRACT

Introduction: Metabolic syndrome is a clinically important cluster of cardiometabolic abnormalities, including central obesity, insulin resistance, dysglycemia, dyslipidemia and hypertension. Because these disturbances are strongly influenced by chronic low-grade inflammation, oxidative stress and lifestyle-related risk factors, interest has grown in adjunctive nutritional strategies, including curcumin supplementation.

Aim: This review aimed to evaluate current clinical evidence on curcumin supplementation in metabolic syndrome and related cardiometabolic disorders, with particular attention to its potential role in prevention-oriented healthcare.

Material and Methods: A narrative review was conducted using PubMed, Scopus and Web of Science. Studies published between 2008 and 2025 were considered, with priority given to randomized controlled trials, systematic reviews and meta-analyses. A total of 25 studies were included.

Results: The strongest evidence concerns glycemic and inflammatory outcomes. Meta-analyses report reductions in fasting blood glucose, HbA1c and C-reactive protein, while effects on lipid profile and anthropometric indices appear more variable and generally modest. Enhanced-bioavailability formulations may produce stronger effects, but they also complicate comparison between studies and raise additional safety considerations.

Conclusions: Curcumin may be considered a potentially useful adjunct to lifestyle-based prevention and cardiometabolic risk management. However, it should not be presented as an alternative to established interventions. Larger, longer and better-standardized randomized trials are needed before firm clinical recommendations can be made.

KEYWORDS

Turmeric, Curcumin, Metabolic Syndrome, Insulin Resistance, Glycemic Control, Inflammation, Nutraceuticals

CITATION

Wiśniewski, P., Buczek, W., Paszke, N., Gajewski, J., Machelski, G., Mędrek, M., Mika, M., & Mąkosa, K. (2026). Curcumin supplementation in the prevention and management of metabolic syndrome: Current evidence and public health perspectives. *International Journal of Innovative Technologies in Social Science*, 3(51). [https://doi.org/10.31435/ijitss.3\(51\).2026.6135](https://doi.org/10.31435/ijitss.3(51).2026.6135)

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Introduction

Metabolic syndrome is a cluster of cardiometabolic abnormalities that includes central obesity, insulin resistance, dysglycemia, atherogenic dyslipidemia and hypertension. These factors frequently coexist and substantially increase the risk of type 2 diabetes (T2D), cardiovascular disease and long-term metabolic complications (Pacholczyk et al. 2008). Because metabolic syndrome is strongly linked to obesity, physical inactivity and dietary patterns, its prevention and management remain closely connected with lifestyle modification. Lifestyle-based interventions, including weight reduction, regular physical activity and improvement of diet quality, remain the foundation of metabolic syndrome prevention. However, in clinical practice, long-term adherence is often difficult, and many patients continue to present with residual metabolic risk despite standard recommendations (Visseren et al. 2021). This has contributed to interest in adjunctive nutritional strategies that may support, but not replace, established preventive measures.

Curcumin, the main bioactive polyphenol of turmeric (*Curcuma longa* L.), has been widely studied because of its anti-inflammatory, antioxidant and metabolic regulatory properties (Gopi et al. 2017). Experimental and clinical evidence suggests that curcumin may influence pathways involved in glucose metabolism, lipid regulation, oxidative stress, inflammatory signaling and adipose tissue function (Den Hartogh et al. 2020). These mechanisms provide a biological rationale for studying curcumin in metabolic syndrome, although biological plausibility alone is not sufficient to confirm clinical effectiveness.

A key limitation of curcumin is its poor oral bioavailability. For this reason, newer formulations, including nano-curcumin, phytosomal preparations and piperine-enhanced products, have been developed to improve absorption and systemic exposure (Heidari et al. 2023). These formulations may increase therapeutic potential, but they also make interpretation of clinical studies more difficult because trials differ in dose, preparation, duration and study population.

Although turmeric has a long history of use in traditional medicine, contemporary recommendations should rely primarily on evidence from randomized controlled trials, systematic reviews and meta-analyses. Therefore, the aim of this review is to summarize and critically evaluate current evidence on curcumin supplementation in metabolic syndrome and related cardiometabolic disorders, with particular attention to glycemic control, lipid metabolism, inflammation, oxidative stress, anthropometric outcomes, safety and preventive healthcare relevance.

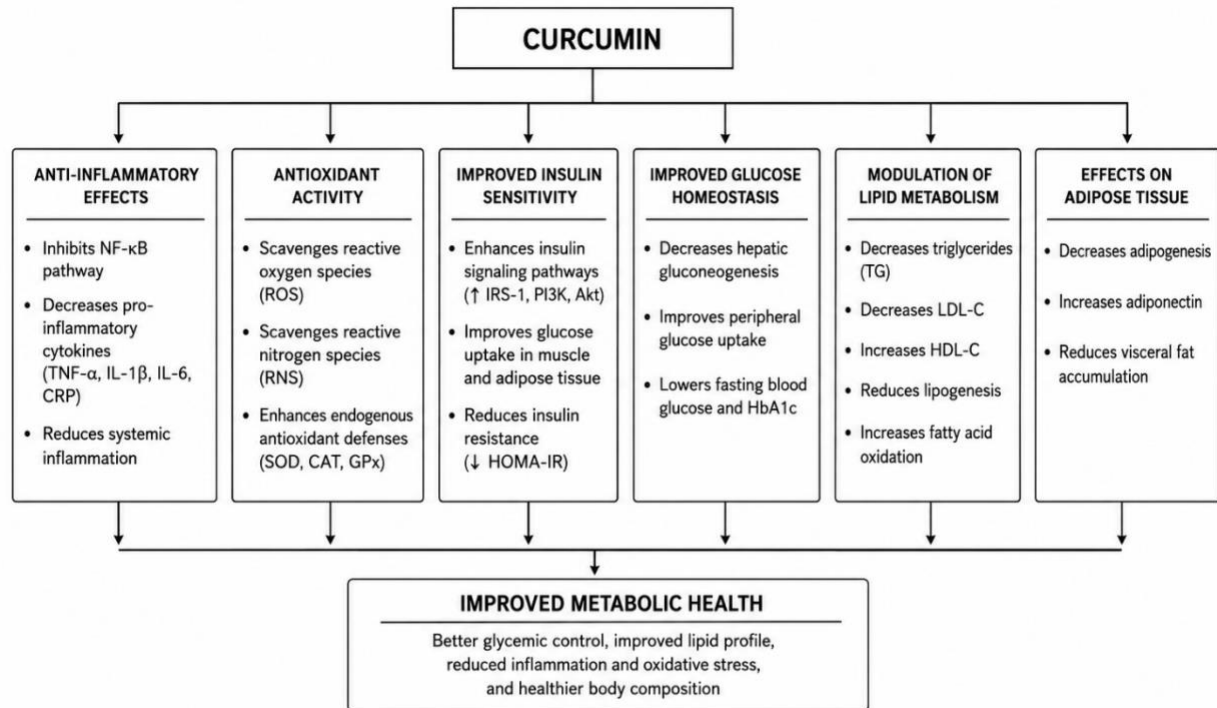


Figure 1. Proposed mechanisms of curcumin action in metabolic syndrome.

CRP – C-reactive protein; HDL-C – high-density lipoprotein cholesterol; HOMA-IR – Homeostatic Model Assessment of Insulin Resistance; IRS-1 – insulin receptor substrate-1; LDL-C – low-density lipoprotein cholesterol; PI3K – phosphoinositide 3-kinase; ROS – reactive oxygen species; RNS – reactive nitrogen species; SOD – superoxide dismutase; CAT – catalase; GPx – glutathione peroxidase; TG – triglycerides.

Fig. 1. Proposed mechanisms of curcumin action in metabolic syndrome. CRP – C-reactive protein; HDL-C – high-density lipoprotein cholesterol; HOMA-IR – Homeostatic Model Assessment of Insulin Resistance; IRS-1 – insulin receptor substrate-1; LDL-C – low-density lipoprotein cholesterol; PI3K – phosphoinositide 3-kinase; ROS – reactive oxygen species; RNS – reactive nitrogen species; SOD – superoxide dismutase; CAT – catalase; GPx – glutathione peroxidase; TG – triglycerides.

Materials and Methods

This narrative review was conducted to evaluate the effects of turmeric and curcumin supplementation on metabolic health outcomes associated with metabolic syndrome, including glycemic control, lipid metabolism, inflammatory markers, oxidative stress, and anthropometric parameters. A comprehensive literature search was performed using PubMed, Scopus, and Web of Science databases. Articles published between January 2008 and March 2025 were considered. The search strategy included combinations of the following keywords and Medical Subject Headings (MeSH) terms: “curcumin”, “turmeric”, “Curcuma longa”, “metabolic syndrome”, “insulin resistance”, “type 2 diabetes”, “glycemic control”, “lipid profile”, “inflammation”, “oxidative stress”, “obesity”, and “body weight”.

The review prioritized evidence from randomized controlled trials (RCTs), systematic reviews, and meta-analyses investigating the metabolic effects of turmeric or curcumin supplementation in adult populations. Observational studies and experimental animal studies were included only when they provided mechanistic insights or supported interpretation of clinical findings. Studies were included if they: investigated turmeric, curcumin, or curcumin-based formulations as an intervention; reported outcomes related to glucose metabolism, insulin sensitivity, lipid profile, inflammatory biomarkers, oxidative stress, body weight, body mass index, or waist circumference; were published in peer-reviewed journals in English. Studies were

excluded if they were conference abstracts, editorials, commentaries, or case reports; did not provide sufficient methodological information; focused exclusively on non-metabolic outcomes unrelated to metabolic syndrome.

Reference lists of eligible articles were manually screened to identify additional relevant studies. Particular emphasis was placed on high-quality meta-analyses and well-designed randomized controlled trials. Information extracted from the included studies comprised study design, sample size, participant characteristics, intervention type and dosage, duration of supplementation, primary metabolic outcomes, and reported adverse events.

Due to substantial heterogeneity among study populations, curcumin formulations, dosages, and outcome measures, a quantitative meta-analysis was not performed. Findings were therefore synthesized narratively, with emphasis placed on the consistency, magnitude, and clinical relevance of reported effects.

Results

3.1. Effects on serum lipids

Evidence regarding the effects of curcumin on blood lipid parameters remains heterogeneous. Earlier meta-analytic work pooling small RCTs found no significant overall effect of curcumin on total cholesterol, LDL-C, HDL-C or triglycerides when considering heterogeneous populations, highlighting important between-study variability in dose, duration and formulation. The double-blind randomized placebo-controlled clinical trial of nano-curcumin in overweight/obese NAFLD patients reported decreased TC, TG and LDL-c levels and statistically significant ($P < 0.05$) increases of HDL-c levels. These findings were included in meta-analysis of nine RCTs, which performed subgroup analysis, reporting several subgroups benefiting from curcumin supplementation, including a significant decrease of TG levels in patients with baseline TG ≥ 150 mg/dL or with BMI > 30 kgm⁻², a significant decrease of TC levels in patients with baseline TC ≥ 200 mg/dL or with BMI > 30 kgm⁻² and significant alteration of LDL-c levels in patients with baseline LDL-C ≥ 100 mg/dL and BMI > 30 kgm⁻².

However, the aforementioned studies demonstrate considerable heterogeneity, varying characteristics of the participants and of the nano-curcumin dosages; as well as absence of any data collected outside of Iran or concerning long-term usage.

3.2. Effects on glycemic markers (HbA1c, FBS, HOMA-IR)

Recent meta-analysis of collected studies conducted between 2008 and 2024 in patients with T2D shows that supplementation with turmeric or its bioactive compound, curcumin - whether in the form of curcumin capsules, nano-curcumin, theracurcumin or pure turmeric powder capsules - produced consistent, clinically meaningful reductions in fasting glycemia and HbA1c in people with established metabolic dysfunction. The study reported decreased fasting blood glucose levels by an average of 11.48 mg/dL (95% CI: -14.26 to -8.70) and decreased HbA1c levels by an average of 0.54% (95% CI: -0.73 to -0.35). However, there was considerable variability between studies: the effect on fasting blood glucose showed higher heterogeneity ($I^2 = 74\%$, $p < 0.01$), while the effect on HbA1c showed moderate heterogeneity ($I^2 = 46\%$, $p = 0.03$).

Additionally, a large, well-conducted RCT in prediabetic adults found particularly striking preventive effects: after 9 months none of the curcumin extract-treated participants progressed to overt type 2 diabetes, whereas 16.4% of placebo recipients did. Additionally, the study demonstrated that curcumin extract improved β -cell function (increased HOMA- β) and reduced insulin resistance (decreased HOMA-IR).

3.3. Effects on C-reactive protein

Findings for the effect of C-reactive protein are heterogeneous, although one recent analysis showed decreases in high-sensitivity CRP (hs-CRP) that were ranging from modest to clinically meaningful. The study demonstrated a decrease in C-reactive protein levels (SMD = -0.59, 95%CI (-1.11, -0.07), $p = 0.03$). However, there was a high level of heterogeneity ($I^2 = 77\%$, $p < 0.01$). Additionally, the study revealed that stronger CRP-lowering effects corresponded to using enhanced-bioavailability preparations such as curcumin-phytosome, nanoparticle formulations, or piperine-enhanced curcumin, as well as that greater CRP reductions corresponded to baseline elevated inflammation compared to healthy individuals.

3.4. Effects on oxidative stress

Evidence regarding the effects of curcumin on oxidative stress is variable. One pooled analysis found modest but consistent reductions ($I^2 = 96.7\%$; $p < 0.001$; SMD -3.14 ; 95% CI $[-4.76, -1.53]$; $p < 0.001$) in MDA (malondialdehyde) - a common marker of oxidative damage. However, the same findings did not show any significant decrease in SOD (superoxide dismutase) levels - another common marker linked to oxidative stress. Another meta-analysis, disease-specific to metabolic syndrome, also reported significant lowering of MDA levels, although the authors caution that the number of low-bias RCTs remains limited and the results may vary by trial quality.

3.5. Effects on anthropometric indices

Clinical trials and pooled analysis generally suggest that turmeric/curcumin supplementation is associated with modest improvements in anthropometric indices including: body weight (BW), body mass index (BMI) and waist circumference (WC). A recent updated umbrella review and meta-analysis of randomized controlled trials has found significant reductions in all three indices used to assess obesity, with mean differences of approximately WMD $= -0.59$ kg for BW, WMD $= -0.24$ kg/m² for BMI and WMD $= -1.32$ cm for WC. In people with diabetes and prediabetes another meta-analysis reported significant reductions in BW, BMI along with reductions in fat mass percentage and waist-to-hip ratio, although the BMI and waist-to-hip ratio were not consistently affected in all subgroups. Importantly, the study showed no effects of turmeric/curcumin on BMI in patients with prediabetes. However, in vivo studies further support anti-obesity effects in turmeric-derived interventions. In a high-fat diet induced obesity rats model, one study showed that administration of 50% fermented *C. longa* ethanol extract for 12 weeks significantly decreased body weight gains, showing promising results for further in vivo experimental tests and for further RCTs of turmeric in obesity. This study suggests that curcumin may downregulate key regulators of adipogenesis and lipid storage, including PPAR- γ , C/EBP- α , and SREBP-1c, while simultaneously upregulating proteins associated with lipolysis and fatty-acid oxidation. The authors also note possible effects of fermenting *C. longa* on potentially enhancing its bioavailability.

3.6 Safety

Clinical trials involving pure turmeric in its natural form have not demonstrated any evidence of toxicity and oral administration of curcumin at doses up to 6000 milligrams per day for 4 to 7 weeks has been reported as safe. Its favorable safety profile has partly been attributed to inherently poor oral absorption. Consequently, it remains uncertain whether conventional oral formulations of turmeric or curcumin achieve sufficient systemic concentrations to elicit either therapeutic or adverse effects. In contrast, many contemporary turmeric supplements incorporate piperine (black pepper extract), which markedly enhances curcumin's bioavailability. For example, co-administration of 20 mg of piperine has been shown to increase serum bioavailability approximately twentyfold, however, such enhanced systemic exposure may, in turn, heighten the potential risk of hepatotoxicity. Newer randomized trials and systematic reviews through 2024–2025 continue to report mostly minor adverse events; a few trials note GI upset as the commonest AE (constipation, nausea and vomiting, stomachache) which generally resolved over time. Although current evidence supports a favorable safety profile, clinicians should exercise caution when recommending high-bioavailability formulations, particularly in individuals with pre-existing liver disease.

Table 1. Summary of Key Evidence on Curcumin Supplementation in Metabolic Syndrome and Related Metabolic Disorders

Study	Study type	Population	Condition	Curcumin formulation	Duration	Key findings
Chuengsamarn et al. (2012)	RCT	Prediabetes	Prediabetes	Curcumin extract	9 months	0% progression to T2D vs 16.4% placebo; improved HOMA- β and HOMA-IR
Jazayeri-Tehrani et al. (2019)	RCT	Overweight/obese NAFLD patients	NAFLD	Nano-curcumin	3 months	↓ TC, TG, LDL-C; ↑ HDL-C
Ashtary-Larky et al. (2021)	Meta-analysis	Meta-analysis of 9 RCTs	Cardiometabolic risk	Various formulations	Various	Improved TG, TC and LDL-C in selected subgroups
Mokgalaboni et al. (2024)	Meta-analysis	Patients with T2D	Type 2 diabetes	Various formulations	Various	↓ FBG by 11.48 mg/dL; ↓ HbA1c by 0.54%
Moradi Baniasadi et al. (2025)	Meta-analysis	Prediabetes/T2D	Anthropometric outcomes	Turmeric/curcumin	Various	Reduced body weight and adiposity measures

FBS – fasting blood glucose; TG – triglycerides; hs-CRP – high-sensitivity C-reactive protein; HOMA-IR – Homeostatic Model Assessment of Insulin Resistance; QUICKI – Quantitative Insulin Sensitivity Check Index; LDL-C – low-density lipoprotein cholesterol; HDL-C – high-density lipoprotein cholesterol.

Discussion

The evidence summarized in this review suggests that curcumin supplementation may have beneficial effects on selected components of metabolic syndrome. However, the strength of evidence is not equal across all outcomes. The most convincing data concern glycemic control and inflammatory markers, whereas effects on body weight, waist circumference and lipid profile are more modest and less consistent (Mokgalaboni et al. 2024; Gorabi et al. 2022; Unhapipatpong et al. 2023).

The effects on glucose metabolism appear clinically relevant, particularly in populations with established metabolic dysfunction. Meta-analytic data indicate reductions in fasting blood glucose and HbA1c, and the trial by Chuengsamarn et al. (2012) suggests a possible preventive effect in individuals with prediabetes. These findings are consistent with proposed mechanisms involving improved insulin sensitivity, reduced inflammatory signaling and better β -cell function. Nevertheless, the impressive results of individual trials should be interpreted cautiously, as replication in larger and more diverse populations is still needed.

The lipid-lowering effects of curcumin are less straightforward. Some analyses report improvements in triglycerides, total cholesterol or LDL-C, especially in individuals with elevated baseline values or obesity, but earlier meta-analytic findings were neutral or inconsistent (Sahebkar 2014; Ashtary-Larky et al. 2021).

This suggests that curcumin is unlikely to act as a broad lipid-lowering agent in all patients. Its potential benefit may be more visible in selected subgroups with higher baseline cardiometabolic risk.

Inflammation and oxidative stress represent plausible therapeutic targets in metabolic syndrome. Reductions in hs-CRP and malondialdehyde support the hypothesis that curcumin may attenuate low-grade inflammatory and oxidative pathways involved in cardiometabolic disease progression (Gorabi et al. 2022; Tabrizi et al. 2019; Qiu et al. 2023). Still, these biomarkers are intermediate outcomes. Their improvement does not automatically translate into reduced cardiovascular events or long-term prevention of diabetes, which have not been adequately assessed in curcumin trials.

Anthropometric outcomes should also be interpreted with caution. Reported reductions in body weight, BMI and waist circumference are statistically significant in some pooled analyses, but the absolute changes are generally small (Unhapipatpong et al. 2023; Moradi Baniasadi et al. 2025). Therefore, curcumin should not be presented as a weight-loss intervention. At most, it may modestly support metabolic improvement when combined with diet, physical activity and broader lifestyle modification.

A recurring problem in this literature is heterogeneity. Studies differ in participant characteristics, baseline metabolic status, intervention duration, dosage and formulation. Enhanced-bioavailability products, such as nano-curcumin, curcumin-phytosome and piperine-containing preparations, may produce stronger effects than conventional formulations, but they also limit comparability across studies (Heidari et al. 2023; Jazayeri-Tehrani et al. 2019). Future trials should therefore clearly report formulation characteristics and use standardized preparations whenever possible.

Safety remains an important issue. Most clinical studies report good tolerability and mainly mild gastrointestinal adverse events (Moradi Baniasadi et al. 2025). However, the assumption that turmeric supplements are automatically harmless is not justified. Reports of turmeric-associated liver injury, particularly in relation to products with enhanced bioavailability or piperine, indicate that safety monitoring is still necessary (Halegoua-DeMarzio et al. 2023). This is especially relevant for patients with liver disease, polypharmacy or long-term supplement use.

Overall, curcumin appears more credible as an adjunctive intervention than as an independent treatment. Its potential value lies in supporting selected metabolic and inflammatory parameters, not in replacing established preventive strategies. Lifestyle modification, weight management and appropriate pharmacotherapy remain the foundation of metabolic syndrome management.

4.1. Public Health and Preventive Healthcare Perspectives

From a public health perspective, curcumin supplementation should be considered within the broader context of cardiometabolic prevention. Metabolic syndrome is closely linked to obesity, sedentary behavior, poor diet quality and population-level changes in lifestyle (Gregory et al. 2019; NCD-RisC 2017). These determinants cannot be meaningfully addressed by supplementation alone. Nevertheless, nutraceuticals may have a supportive role in selected individuals, especially when they are used alongside evidence-based lifestyle interventions (Mokgalaboni et al. 2024; Moradi Baniasadi et al. 2025). Curcumin may be relevant in people with prediabetes, early metabolic dysfunction, obesity-related inflammation or elevated cardiometabolic risk. Its possible advantages include relatively low cost, wide availability and a generally favorable tolerability profile. However, these advantages must be balanced against the variability of commercial preparations and the limited evidence on long-term outcomes.

Patient education is essential. Individuals using curcumin should understand that supplements differ in formulation and bioavailability, and that “natural” does not necessarily mean risk-free (Heidari et al. 2023; Ekor 2014; Halegoua-DeMarzio et al. 2023). They should also be informed that curcumin is not a substitute for medical care, dietary change, physical activity or pharmacological treatment when these are indicated. Future public health research should move beyond short-term biomarker changes. Studies should assess adherence, safety, cost-effectiveness, product quality, interactions with medications and long-term cardiometabolic outcomes. Without such evidence, curcumin should remain a promising but not definitive component of preventive healthcare.

4.2. Limitations

Several limitations of the available evidence should be acknowledged. First, many randomized controlled trials included relatively small sample sizes and short intervention periods, limiting the assessment of long-term efficacy and safety. Second, substantial heterogeneity exists among studies with respect to participant characteristics, baseline metabolic status, curcumin formulations, dosages, treatment duration, and outcome measures. Third, enhanced-bioavailability preparations such as nano-curcumin, phytosomal formulations, and piperine-containing products differ considerably from conventional curcumin preparations, making direct comparisons challenging. Furthermore, publication bias cannot be excluded, as studies reporting positive outcomes may be more likely to be published. Finally, although current evidence suggests a favorable safety profile, long-term safety data remain limited, particularly for high-bioavailability formulations. These limitations should be considered when interpreting the overall findings of this review.

5. Conclusions

Curcumin supplementation may have a supportive role in the prevention and management of metabolic syndrome, particularly in relation to glycemic control and inflammatory markers. Evidence from randomized controlled trials and meta-analyses suggests that curcumin can reduce fasting blood glucose, HbA1c and selected inflammatory biomarkers in patients with metabolic dysfunction, prediabetes or type 2 diabetes (Mokgalaboni et al. 2024; Gorabi et al. 2022; Qiu et al. 2023). The evidence for lipid metabolism and anthropometric outcomes is less consistent. Some studies report improvements in triglycerides, total cholesterol, LDL-C, body weight, BMI or waist circumference, especially in selected subgroups with higher baseline cardiometabolic risk. However, the absolute effects on body weight and central adiposity are generally modest and should not be overinterpreted (Ashtary-Larky et al. 2021; Unhapipatpong et al. 2023; Moradi Baniasadi et al. 2025). Curcumin should therefore not be presented as a weight-loss intervention or as an alternative to lifestyle modification.

The potential metabolic effects of curcumin are biologically plausible. Available evidence points to several possible mechanisms, including modulation of inflammatory pathways, reduction of oxidative stress, improvement of insulin sensitivity, regulation of lipid metabolism and interactions with the gut microbiota (Den Hartogh et al. 2020; Vafaeie et al. 2025; Konaktchieva et al. 2025). Nevertheless, mechanistic plausibility does not eliminate the need for well-designed clinical trials assessing long-term outcomes. An important limitation of the current evidence is the heterogeneity of curcumin formulations, dosages, treatment durations and study populations. Enhanced-bioavailability preparations, including nano-curcumin, phytosomal formulations and piperine-containing products, may produce stronger biological effects, but they also make comparisons between studies more difficult and raise additional safety considerations (Heidari et al. 2023; Halegoua-DeMarzio et al. 2023).

Overall, curcumin is best understood as a possible adjunctive component of cardiometabolic risk management, not as a stand-alone treatment. Its use may be considered in selected individuals as part of a broader strategy that includes dietary improvement, regular physical activity, weight management, risk factor control and standard medical care when indicated. Further research should focus on larger randomized controlled trials using standardized formulations, clearly defined patient populations and longer follow-up periods. Future studies should also evaluate long-term safety, clinically meaningful outcomes, medication interactions, adherence, cost-effectiveness and the practical role of curcumin supplementation within preventive healthcare.

Disclosure: The authors declare that they have no relevant financial or non-financial interests to disclose

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All authors have read and agreed with the published version of this manuscript.

Funding statement: The study did not receive special funding.

Conflict of Interest Statement: The authors report that there are no conflicts of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process: In preparing this work, the authors used ChatGPT for linguistic corrections, i.e., grammatical and stylistic corrections in English. After using this tool/service, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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